A DRIFT BOTTLE STUDY OF THE SOUTHERN MONTEREY BAY

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A DRIFT BOTTLE STUDY
OF THE SOUTHERN MONTEREY BAY

by

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September 1973

A Drift Bottle Study of the Southern Monterey Bay

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL

ABSTRACT

2100 drift bottles were dropped at five stations in southern Monterey Bay twice per drop day over a period of 14 months. 47.7% (1002) were recovered. Over 99% of the recoveries were made in the bay. The indicated circulation in the southern bay agrees with models driven by wind stress and momentum transfer from the offshore ocean currents. A significant difference was found between the morning and afternoon drops with the morning drop returns being larger and found closer to the drop point. The afternoon returns were more widely dispersed in the direction of the ocean-driven component of the coastal current. The diurnal variation of the bottle returns is attributed to the diurnal seabreeze regime. The predominant northwest winds, modified by the seabreeze, appear to generate a counterclockwise circulation along the coast in the southern end of the bay. The drift bottles seem to follow the coastal portion of the Garcia (1971) model of the ocean-driven component of the circulation. This is counterclockwise with the California Current flowing offshore and clockwise when the Davidson Current flows. Current velocities appear to be between 0.2 and 0.4 knots.

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ACKNOWLEDGEMENTS

I would like to express my appreciation to Professor Warren C. Thompson, my thesis advisor, for all the time and help he has given me. Not only did he make the data for this study available to me, but also spent many hours of his time directing me in the preparation of this thesis.

I. INTRODUCTION

A. PURPOSE

The purpose of this study is to extend the knowledge of the surface circulation of Monterey Bay, particularly the southern portion of the bay. The area where this study was carried out is an area of high population density. Two sewage outfalls for the cities of Monterey and Seaside have released floating materials into the nearshore waters. Monterey Harbor also provides a source of flotsam and pollutants. Del Monte Beach, a major recreational beach in the southern bay, was for a time closed to swimmers by the Monterey County Public Health Department because of high coliform bacteria counts in the water. No current observations have been made off Del Monte Beach or Cannery Row that reveal the prevailing flow patterns, although it is believed that the circulation in this recessed portion of Monterey Bay is weak or non-existent.

Monterey Bay is an important tourist and fishing area along the central California coast. There are also some industries along the bay shore including a major power plant at Moss Landing. The population of the bay area is growing, and to achieve the optimum location for industrial and municipal facilities, things such as industrial and sewage outfalls, thermal discharge, and harbor pollution must be placed or controlled so as to minimize adverse effects. To achieve this, a knowledge of the circulation patterns of the bay is needed.

B. DESCRIPTION OF MONTEREY BAY

Monterey Bay is a nearly semi-elliptical embayment in the coastline of Central California (Figures 1 and 3). It is approximately 20 nautical miles long from north to south and has a maximum indentation into the open coast of about 10 nautical miles. The seaward limit of the bay may be approximated by a line running from Point Pinos to Point Santa Cruz.

The bay is an area of wide flat continental shelf bisected by the deep intrusion of the Monterey Submarine Canyon which has its head very close to shore off Moss Landing. It can be considered to be composed of three physiographic units: the northern and southern shallow shelves and the canyon. The shallow regions are less than 100 meters deep and exceedingly flat while the submarine canyon has very steep sides and reaches depths of over 1500 meters within the bay. The presence of the canyon allows deep oceanic water access along the center of Monterey Bay.

Skogsberg (1936) made the first comprehensive oceanographic investigation of the circulation regime in Monterey Bay. He occupied 23 stations located in the bay, taking measurements of temperature, salinity, and other chemical data. From his study, he was able to divide a year into three oceanographic seasons. These have come to be known as the Upwelling period, the Oceanic period, and the Davidson Current period. Bolin (1964), in a study of one station over the Monterey Submarine Canyon for a five-year period, confirmed Skogsberg's work and refined the definition of these oceanographic seasons.

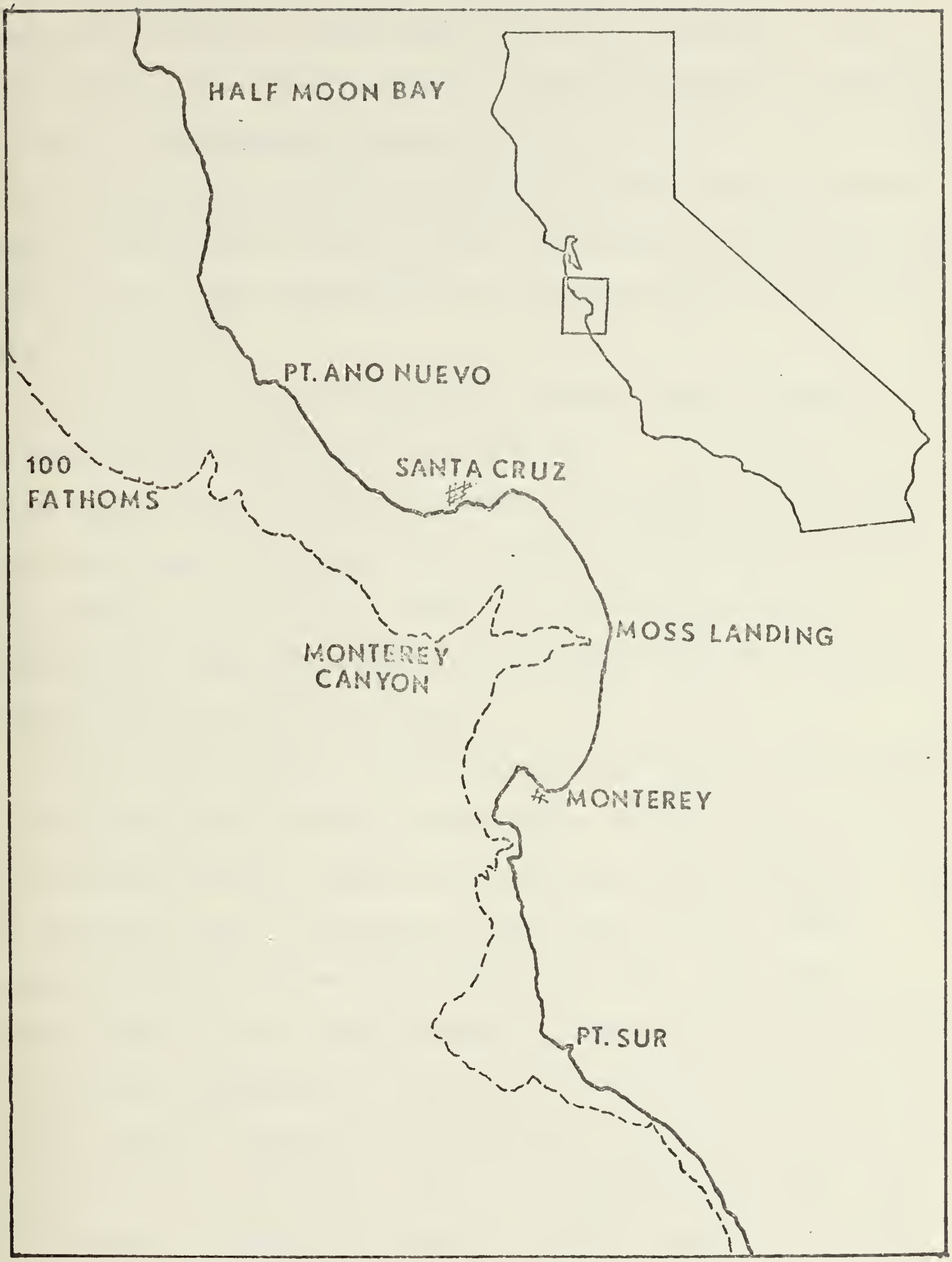

Figure 1. Location of Monterey Bay

The Upwelling period generally begins in mid-February or March and extends to late August or early September. Upwelling reaches a maximum in April or May and begins to decrease in June. The Upwelling period is characterized by the ascending of cold subsurface water from depths as great as 150 meters causing the depths of the various isotherms to become shallower. The surface water temperatures are between 10° to 11° C in much of the bay.

The Oceanic period tends to be rather short, usually occurring from September to mid-November. It is characterized by a strong vertical temperature gradient in the upper 100 meters and the highest sea surface temperatures of the year reaching over 13°C. Both the Upwelling and Oceanic periods are associated with the southerly flow of the California Current along the coast.

From mid-November to mid-February or March the northward-flowing Davidson Current is important. During this period, this countercurrent flows at the surface near the coast. It is believed that the Davidson Current may flow at depths greater than 200 meters throughout the year, reaching the surface only in the winter months. There are some indications from CalCOFI geostrophic computations (Wylie, 1966) and drift bottle results (Crowe and Schwartzlose, 1972) that there may sometimes be a northerly flow at the surface at other times of the year. During the Davidson Current period, the upper 50 meters tend to be well mixed and the vertical temperature gradient weak. Surface temperatures are usually lower than in the Oceanic period, but not as low as those occurring during the Upwelling period.

The oceanic seasons are averaged over a number of years, and for an individual year the time of onset and termination of these seasons can vary by as much as a month or two due to changes in the driving forces that cause them.

The prevailing winds in the area tend to correspond with the direction of the oceanic current. During the Davidson period, the prevailing winds are from the south or southwest while during the rest of the year when the California Current dominates the coastal circulation, north or northwest winds predominate.

It is expected that rotary tidal currents occur in the bay, but they have never been measured. The tides exhibit a diurnal inequality with a mean range from mean high water to mean low water of 1.16 meters and a diurnal range between mean higher high water and mean lower low water of 1.68 meters.

II. DRIFT BOTTLE SURVEY

A. SURVEY DESIGN AND CONDUCT

The drift bottle survey described herein was conducted by Professor Warren C. Thompson of the Naval Postgraduate School as a means of studying the circulation of southern Monterey Bay near Monterey Harbor. Personnel involved in the field work include technical assistants of the Naval Postgraduate School and employees of the City of Monterey. The analysis was carried out by the writer. Boats to drop the bottles were provided by both the Naval Postgraduate School and the City of Monterey. The field work was supported by an Office of Naval Research Institution Grant to the Naval Postgraduate School.

Drift bottles were released at five drop points in the extreme southern end of the bay at approximately three-week intervals over a period of study of slightly more than one year. The drop stations, shown in Figure 2, were chosen for the following reasons. Two drop points, designated M and S, were located near the seaward end of the Monterey and Seaside outfalls off Del Monte Beach and are considered to reasonably represent the source of any floating effluent from these two facilities. Station H, located off Monterey Harbor entrance, represents the source of floating materials emanating from the harbor. Station C, off Cannery Row, was located so as to give some control on the circulation to the west of the harbor.

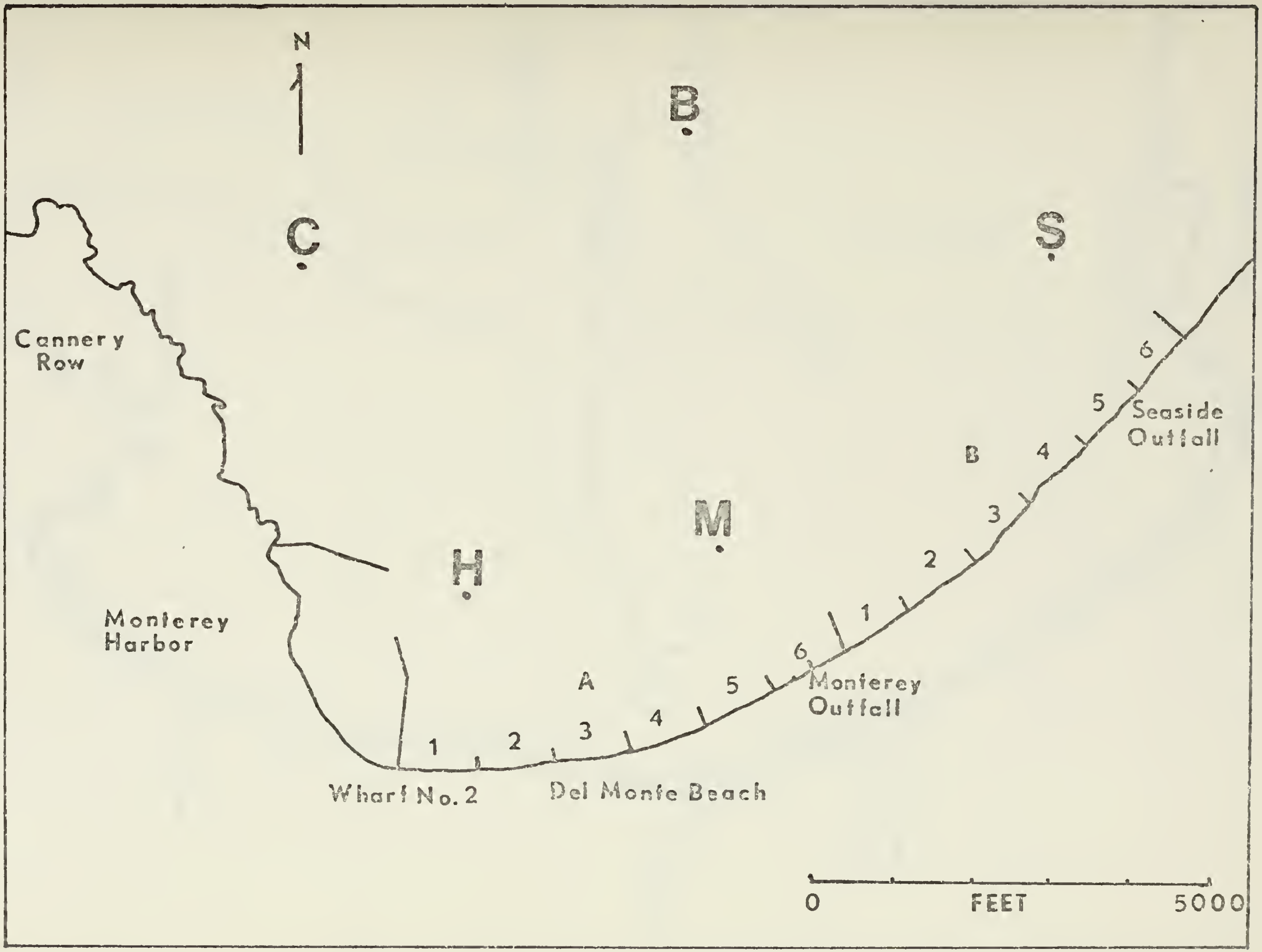

Figure 2. Drift Bottle Release Stations

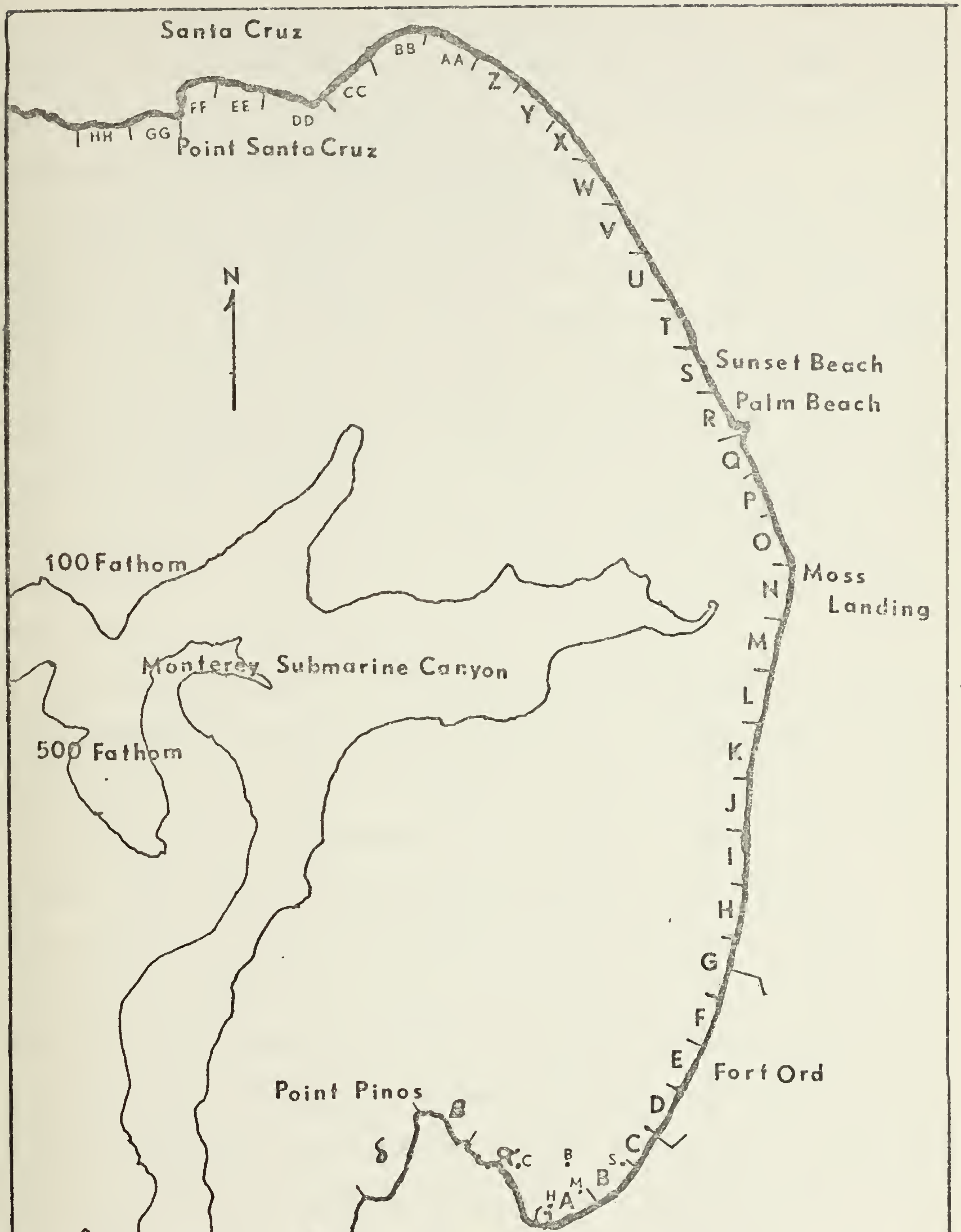

Figure 3. Designation of Coastal Segments for Drift Bottle Returns

Station B, located at a fixed navigation buoy, was designated because it was considered to be indicative of more open bay conditions and to complement the current information to be obtained at the four inshore stations.

Beginning on 11 April 1963 and continuing through 14 May 1964, the bottle drops were made on 18 days. The interval between drops was 21 days with two exceptions when the interval was 33 and 42 days. Two sets of bottle drops were made on each drop day (except on January 30, 1964), one set being released in the morning and the other in the afternoon. Each set consisted of 12 bottles released at each of the five stations for a total of 60 bottles per set. A total of 2100 bottles were released during the investigation.

The 21-day interval between bottle drop dates was chosen as a compromise between the objective of obtaining the best possible picture of the seasonal circulation pattern in the southern portion of Monterey Bay and the amount of time and effort that could be reasonably devoted to this objective. The purpose of two sets of drops on each drop day, in the morning and afternoon, was to determine if there is a significant diurnal variation in the transport of floating materials in response to the marked diurnal variation of winds observed in this nearshore environment. It was believed, in designing the field study, that because of the close proximity of the bottle release stations to shore, a higher percentage of bottles released in the afternoon when the prevailing northwest sea breeze is strongest much of the year would come ashore on Del Monte Beach due to the onshore wind.

The bottles used were 10 ounce NO DEPOSIT NO RETURN soda bottles about eight inches in height. The bottles were filled, on a mass-production basis, with a measured volume of dry, well sorted dune sand. A franked postcard for the finder to mail was enclosed and then the bottle was capped using a capping machine. A picture of the bottle and card is shown in Figure 4. The bottles were checked for flotation before they were used. The end result was a bottle which floated vertically with its neck extending above the water surface about an inch. The direct effect of the wind on the bottle was considered to be negligible. The bottle caps were tight enough to keep salt water from entering the bottle although the caps do rust over a period of time when exposed to salt water. It is presumed that the caps lasted long enough for the bottles to reach the coast locally without sinking due to leakage.

The postcard enclosed in the bottles briefly explained the purpose of the study and asked for the date, time and location where the bottle was found. A telephone number was also provided in case the finder wished to report the information in this manner. The cards were supplied by the City of Monterey. The postcards and telephoned information were collected by the City Engineer's office in Monterey and turned over to the project personnel at the Naval Postgraduate School for analysis. The cards were numbered sequentially starting with 100.

2332 RESEARCH PROJECT ON OCEAN CURRENTS

This bottle is one of several hundred release in Monterey Bay to study ocean currents. The exact place and date of release are recorded, and may be obtained upon request.

You can help us by furnishing the information requested below, and mail, or Phone FR 2-8121, Ext. 10. Date and Hour Found____________________

Where found (exact location, giving important landmarks)____________________

____

____

Name and Address____________________

____

Thank you for this important information.

Figure 4. Drift Bottle and Card

B. DRIFT BOTTLE LIMITATIONS

Drift bottles provide a relatively inexpensive means of studying surface currents over a long period of time; however, there are a number of problems inherent in the method. First of all, only the beginning and endpoints of the drift are known. There is no direct information about the path taken. The bottle trajectories could vary from being straight and direct to a highly convoluted path. The actual time the bottle is adrift is unknown. The investigator knows only the drop time and the pick up time. A bottle could remain on the beach for anywhere from minutes to weeks before being found. Recovery times must be viewed carefully before any conclusions can be drawn from them. A bottle might also wash up on the beach and later wash off and be found somewhere else, thereby giving no indication of the initial event, although this case is probably rare. Field observations (W. C. Thompson, personal communication) show that longshore currents may also have a significant effect on the final placement of the bottle by transporting it a considerable distance along the shore after it enters the surf zone. This factor is particularly important with regard to bottles transported directly ashore on Del Monte Beach under the influence of an onshore wind. Only the net motion of the bottles is known so that it is impossible to determine short-term changes in the current speed and direction.

Another problem that may be important is the possibility of a bias being incorporated in the distribution of the bottles returned such that the probability of a bottle that comes

ashore in one area being found may be significantly different from that of a bottle that comes ashore in another area. Two factors that may be important in causing a bias are the type of shoreline on which the bottles may come ashore and the density of people along the coast. A rocky shoreline might cause the breakage of bottles in the surf so that a smaller percentage would be returned from that area. A lack of people visiting a beach due to inaccessibility or because there are few people in the area may also cut down on the returns; on the other hand, the effect of infrequent visitors to an area may be to lengthen the bottle discovery time without significantly reducing the total returns. A storm or stormy season may also reduce the number of persons on a beach temporarily. These biases, if they exist, cannot be accounted for by a quantitative correction factor but can only be included subjectively in evaluating the data.

For this study, the effect of any bias in the data is probably rather small within Monterey Bay itself. From Wharf No. 2 in Monterey to within two miles of Santa Cruz the coast is fronted completely by sandy beaches so that bottle breakage should be negligible. Although some areas are not visited as often as others, all areas are probably visited often enough so that few or no bottles are lost by burial under wind-blown sand or in any other conceivable way. The apparent time of travel may be effected however. One area in the bay which is restricted to walkers at various times, is the beach adjacent to the Fort Ord firing ranges.

Occasionally, large numbers of bottles were found on this shoreline. The record for recoveries is 52 bottles returned the same day by a soldier from a two-mile stretch south of the Fort Ord NCO Club.

In the vicinity of Santa Cruz and to the north, somewhat more than half the coast is rocky and not very accessible. Only two bottles were returned from this area. South of Carmel for 80 miles most of the coast is very inaccessible, rocky, and sparsely populated so that it would be expected that very few bottles would be recovered in this area. Only one bottle was recovered south of the Monterey Peninsula and it was found at Morro Bay.

There is another factor which might be described as a human factor in the returns. This has to do with incomplete or incorrect information provided by the finder. In regard to the former, the time was not always given or was only generally stated, and in a few instances the location was vague, such as Monterey Bay. A few returns were made at sea with only a rough indication of the recovery location given. For about 97% of the bottles returned, the information was complete, and the useful information from the other 3% was considered wherever possible. On two occasions, people gave information which was obviously intentionally false. Those cases which were blatantly false or had no useful information were discounted as far as time and location, but were counted in the number of returns since they were recovered.

III. DRIFT BOTTLE STATISTICS

A. DESIGNATION OF COASTAL SEGMENTS

In order to represent the distribution of the bottle returns along the coast, it was decided to divide the shoreline into segments of one nautical mile length starting at Wharf No. 2 in Monterey and extending upcoast to near Point Santa Cruz. These were designated with letters of the alphabet and after these were exhausted, by double letters (AA, BB, CC, etc.), as shown in Figure 3. West of Wharf No. 2 the coastal segments were designated by Greek letters and were delimited by prominent points along the rocky coast rather than by distance. Only three bottles were found outside the limits of these designated segments.

The bulk of the returns were found to be in sectors A and B on Del Monte Beach so it was felt that a better picture of the distribution would be produced by breaking these sectors down further. Conveniently, there had been a survey carried out along Del Monte Beach at the time of the drift bottle study which permitted the locations of the bottle returns to be determined within a few feet with respect to Wharf No. 2. Accordingly, Del Monte Beach was subdivided into units approximately 1000 feet long, thereby dividing segments A and B into six units each. Many of the reported bottle recoveries were given in terms of this locating system and most of the others could be similarly identified. The location of these shoreline units is shown in Figure 2.

B. DRIFT BOTTLE RETURNS FROM ALL STATIONS

1. Gross Returns

The overall bottle return from this study was relatively high compared with other drift bottle studies. 1002 bottles out of 2100 dropped were recovered, for a net return rate of 47.7%.

A CalCOFI drift bottle study (Crowe and Schwartzlose, 1972) had a recovery rate of only 3.4% from 148,384 bottles dropped off the California coast over a period of 17 years. However, these drops were up to several hundred miles offshore. Another study carried out in the Gulf of Mexico by Tolbert and Salsman (1964) had a return of 29% for 951 bottles released. This was considered to be higher than normal for coastal regions. A third study done by Burt and Wyatt (1963) off the coast of Oregon resulted in 12.9% returns out of 6,207 bottles dropped. The larger portion of these returns came from the drop points closest to the shore.

A study similar to that described here was done in Santa Monica Bay in 1955 and 1956 (Tibby, 1960). Santa Monica Bay is similar to Monterey Bay in size and shape and in bottom topography, since it also has broad shelves and a submarine canyon. The canyon is located in a different part of the bay, however, and the circulation patterns deduced were different. Out of 5,236 drift cards released over the course of a year, 36% were recovered. Their drop points were further offshore and they had more recoveries outside of Santa Monica than were found outside of Monterey Bay for this study. Returns

for drift card stations closer to shore were generally higher than for those further offshore.

In comparison with all of these studies, the return for the Monterey Bay study is large, but it must be noted that the drop points were closer to shore.

2. Return Locations

Upon examining the distribution of the returns from all stations, shown in Figure 5, it is apparent that very few bottles were found to the west of Wharf No. 2 and that even fewer bottles were found outside of the bay. In fact, only three bottles were found outside the designated shoreline segments shown in Figure 3. Only nine out of 1000 bottles returned were found outside of the bay area as delimited by Point Pinos and Point Santa Cruz. Most of the recoveries were made from Wharf No. 2 to the northern boundary of Fort Ord.

Over 99% of the returns came from inside the bay which would seem to indicate that most of the water of this small area tends to move up the coast and to deposit the bottles along the way. Over 90% of the recoveries took place south of the center of the bay at Moss Landing suggesting that the movement northward along the coast may be largely confined to the area south of Moss Landing. A secondary peak is found at Palm Beach-Sunset Beach area (coastal sectors R and S) suggesting that there may be a separate circulation cell in the northern end of the bay.

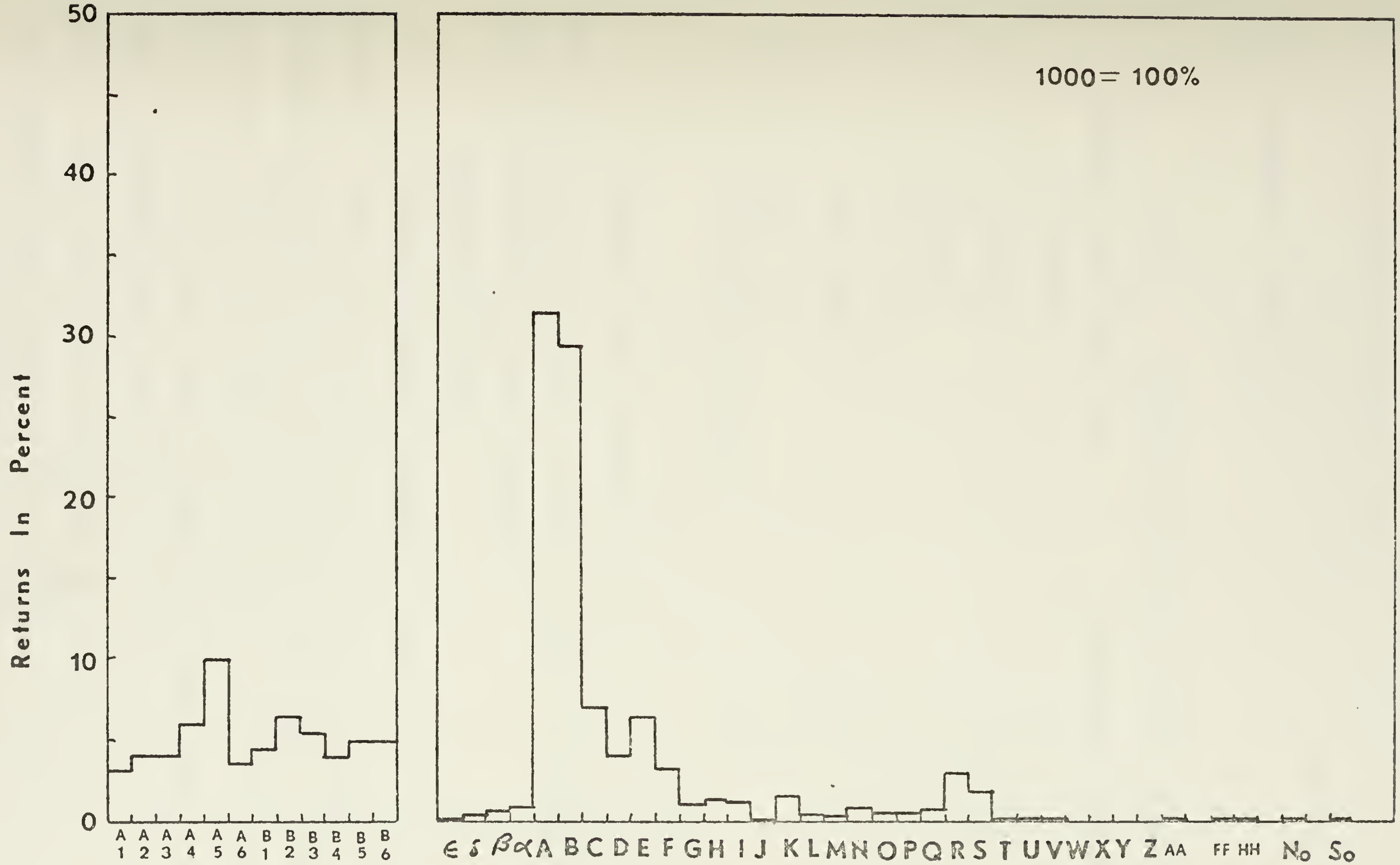

Figure 5. Distribution of Bottles From All Drop Points

3. <u>Return Times</u>

Bottle recovery times are summarized in Table 1 below and are contained in greater detail in Appendix C. Recovery times of less than an hour occurred for drop points M and H for a number of bottles.

TABLE I: SUMMARY OF BOTTLE RECOVERY TIMES

Elapsed Recovery Time	Cumulative Returns
< 5 hours	13.3%
< 10 hours	24.9%
< 30 hours	50.2%
< 100 hours	81.2%
< 200 hours	88.3%
< 300 hours	95.3%
< 600 hours (25 days)	98.1%

In view of the relatively quick recovery for most of the bottles, any loss due to deterioration of the bottle cap was not considered to be a problem.

4. <u>Bottle Drift Rates</u>

An apparent drift rate was determined for each bottle returned. This was obtained by dividing the straight-line distance from drop point to pick-up point by the elapsed time. Since the drift path taken by the bottle is usually longer than the direct path and the apparent travel time shorter than the actual drift time, and since the bottle may have lain on the beach for a period of time before being recovered, the computed drift rate must be considered a minimum speed.

The highest minimum rate of travel measured was 19.9 cm/sec or about 0.4 knots. This was for the bottle returned from Morro Bay. The highest travel rates in the bay were in the range of 16 to 18 cm/sec. These were quite rare. About 8% of the returns indicated speeds of 8 cm/sec or greater. Speeds of 2 to 6 cm/sec were common and make up the bulk of the calculated values. Appendix D presents a list of the five largest apparent drift speeds for each drop.

In view of the fact that these speeds are minimums, the largest speeds computed are most likely to represent actual drift rates. Accordingly, it would appear that speeds of 12 to 20 cm/sec (0.25 to 0.40 knots) are probably representative of the current velocities in southern region of Monterey Bay.

5. Returns by Drop Date

The total number of returns for each drop date are shown in Figure 6. A great deal of variability may be noticed from drop to drop. There appears to be a pattern during the year such that returns are generally highest from March to May remaining relatively high until early September. A low point is reached in September through mid-November, followed by a rising trend until the spring peak is again reached. This pattern is generally coincident with the oceanic seasons, as illustrated in the figure. The association of bottle returns with the oceanic seasons is examined in detail in Section IV.

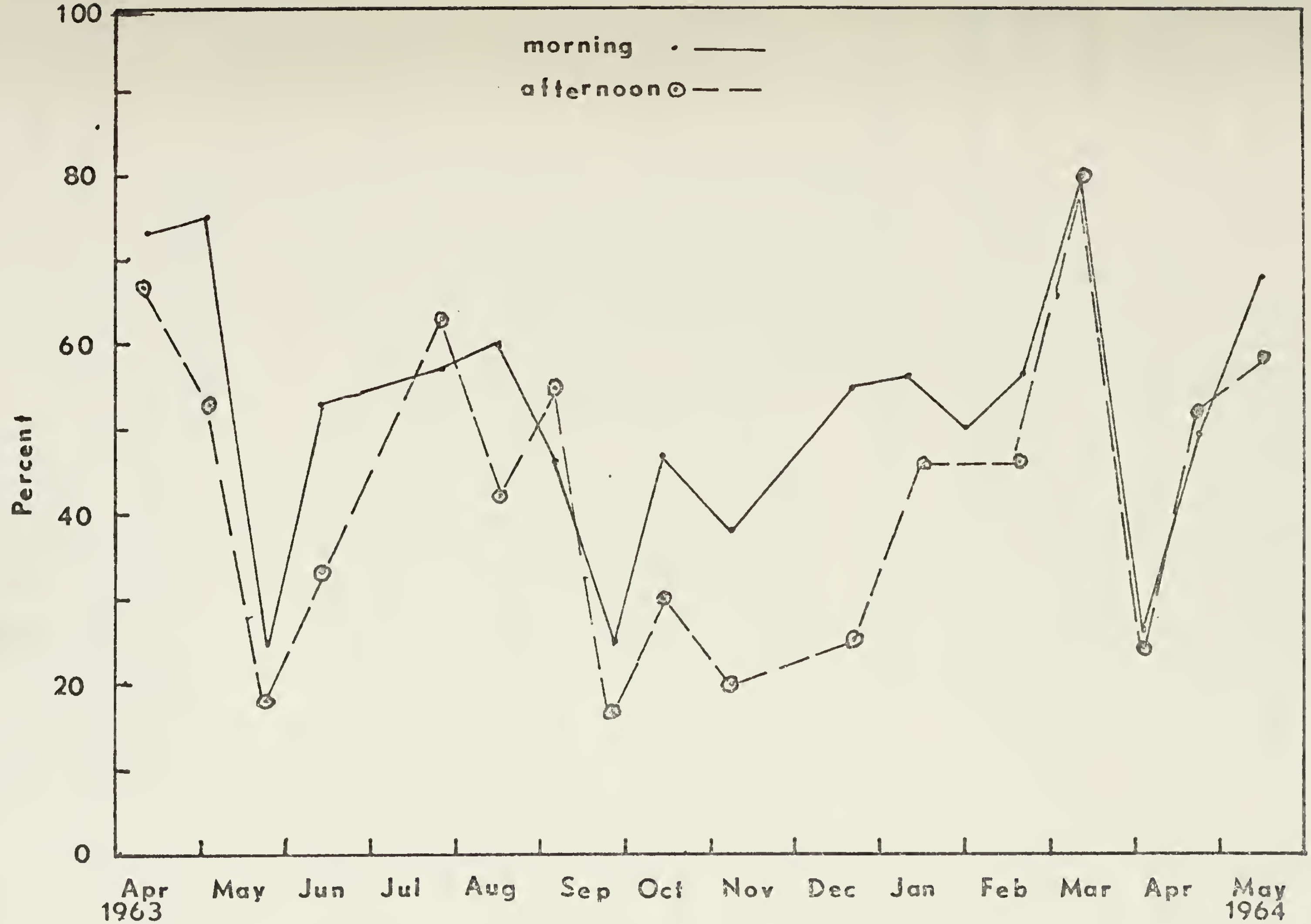

Figure 6. Bottle Returns versus Drop Date (Overall)

6. Morning Versus Afternoon Returns

A comparison between the returns from the morning and the afternoon drops for each drop date may also be seen in Figure 6. It may be noted that the morning drop return rate was larger than that for the afternoon drops in thirteen out of seventeen drop dates. The morning drop return rate was 10% higher on the average than for the afternoon drops, but ranged up to 30% higher for individual drops. The diurnal sea breeze pattern may be the cause of this difference. This is discussed in greater detail in Section V.

C. DRIFT BOTTLE RETURNS BY DROP STATION

1. Gross Returns

The percentage of total returns from the five drop points varied between 38.1% and 60.0%. Drop point B, the farthest from shore, had the lowest percentage of recoveries at 38.1%. Station C had 41.9% returns, which is the second lowest rate for the five drop points. Although C is close to the shore at Cannery Row, the predominant recovery area was Del Monte Beach, making C the second most distant station from shore. S, M, and H had returns of 46.9%, 60.0%, and 51.7%, respectively. These stations are all close to Del Monte Beach.

2. Return Locations

The bottle return locations for the five stations are shown in Figures 7-11. The reader may see that the majority of the bottle recoveries were made on Del Monte Beach, rather close to the drop points. This is especially

true for the drop stations close to Del Monte Beach, making the distribution of returns particularly peaked for stations H, M, and S. Stations B and C which are much farther from Del Monte Beach have a broader distribution of returns. It is important to note that the majority of the returns from drop point C were not found on the closest shore, but on Del Monte Beach at a distance equal to that for returns from drop point B.

Drop points B, C, and S had their peak returns in sector B, while H and M had their peak returns in sector A. For all five drop points, more than 75% of the returns came from Monterey Wharf No. 2 to the north boundary of Fort Ord (sectors A-F), and more than 90% came from the wharf to Moss Landing (sectors A-N). A small secondary peak of returns was centered at Palm Beach (sector R). Only 0.8% (8) of the bottles were found north of sector S so that this sector is effectively the northern limit of the bottles returned from Monterey Bay.

Very low returns were made west of Wharf No. 2 for all drop points. No bottles were found in this area from drop point S and only a few from drop points H and M. Even drop point C which is located offshore from this area had only 3.5% of its returns in sector α.

No bottles left the bay from drop points H and M and only a very few from the other three stations drifted out. Several bottles from drop point C and one from B were found on the seaward side of the Monterey Peninsula. A bottle from drop point B moved northward to Pigeon Point north of

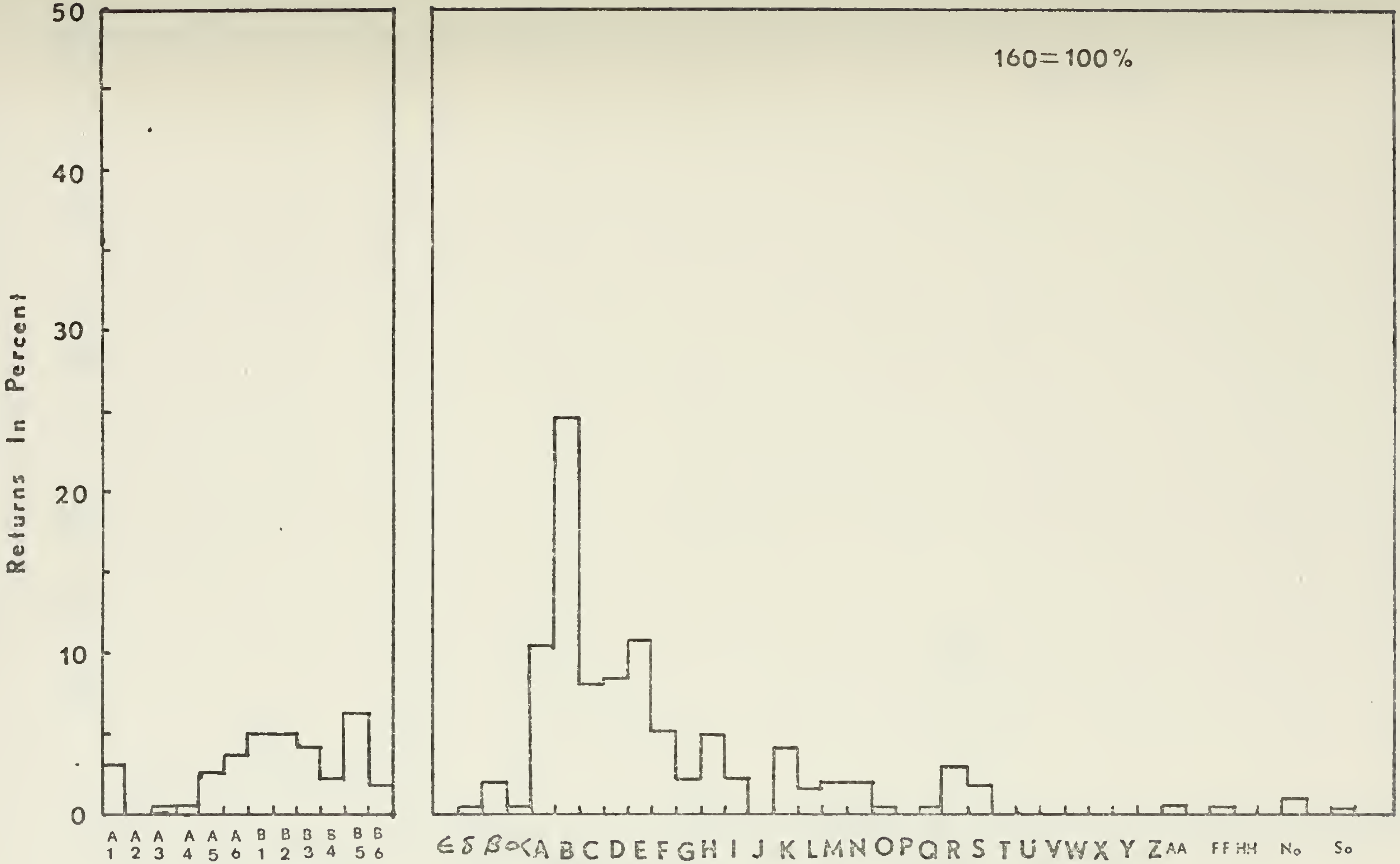

Figure 7. Distribution from Drop Point B (Overall)

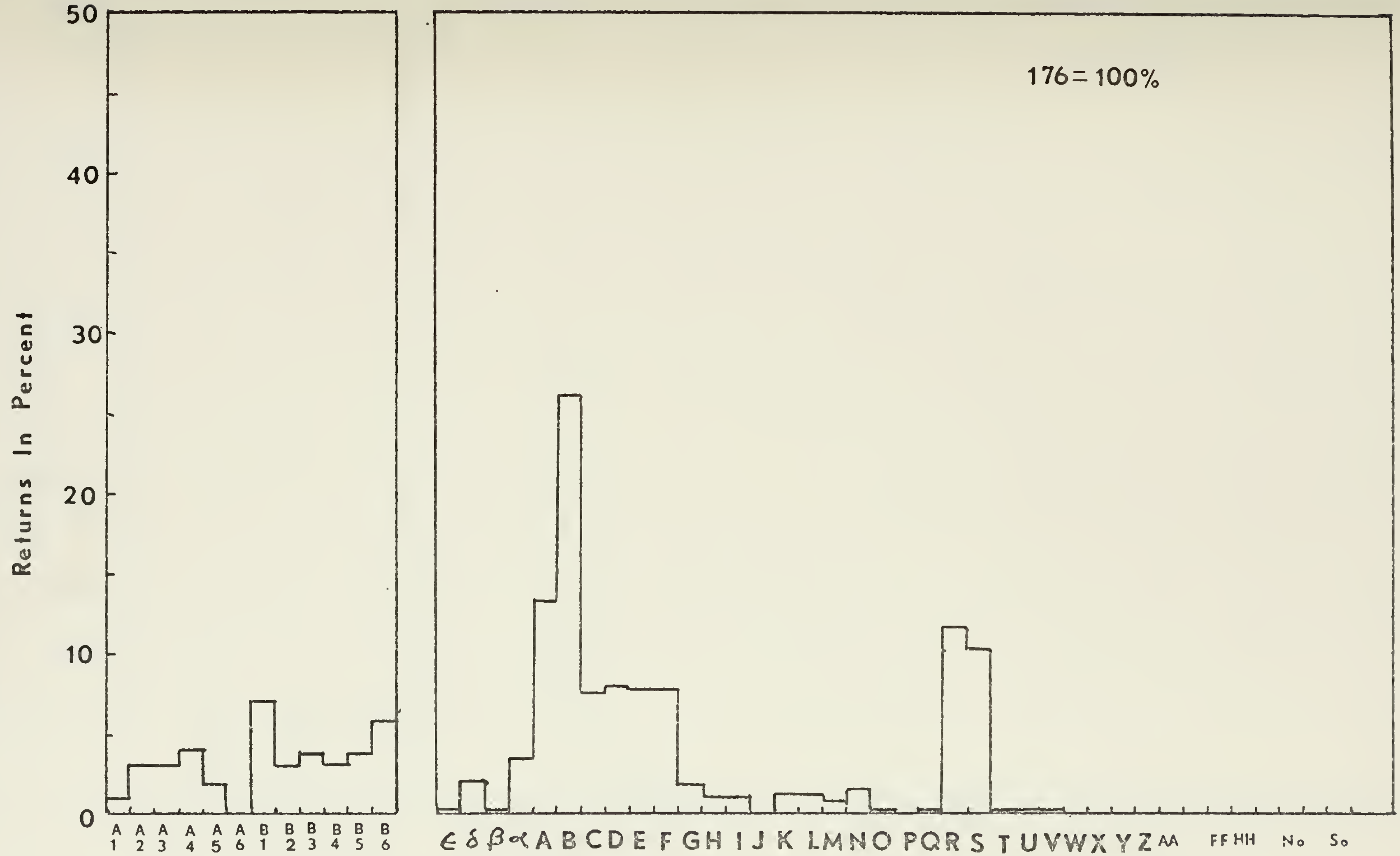

Figure 8. Distribution from Drop Point C (Overall)

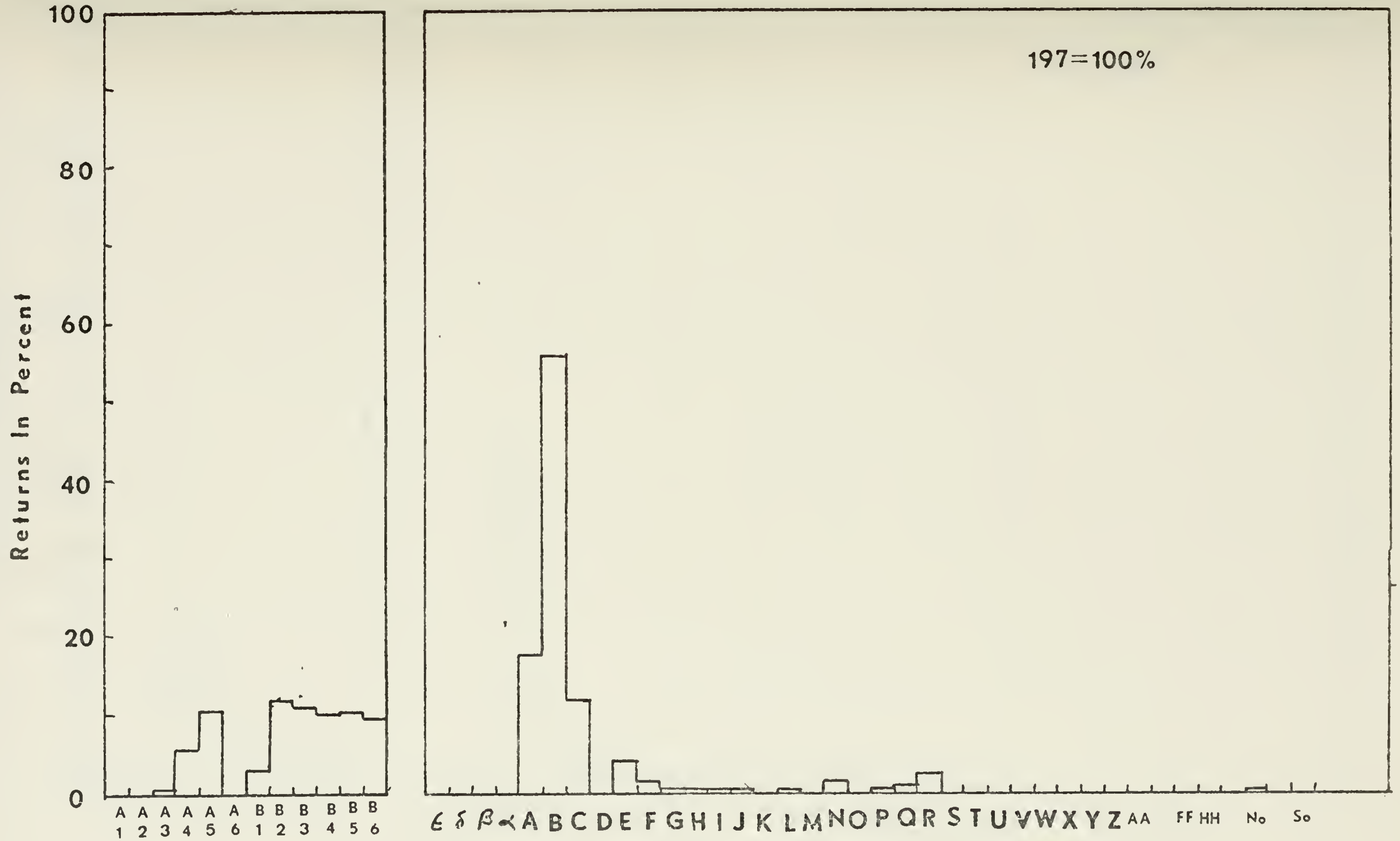

Figure 9. Distribution from Drop Point S (Overall)

Figure 10. Distribution from Drop Point M (Overall)

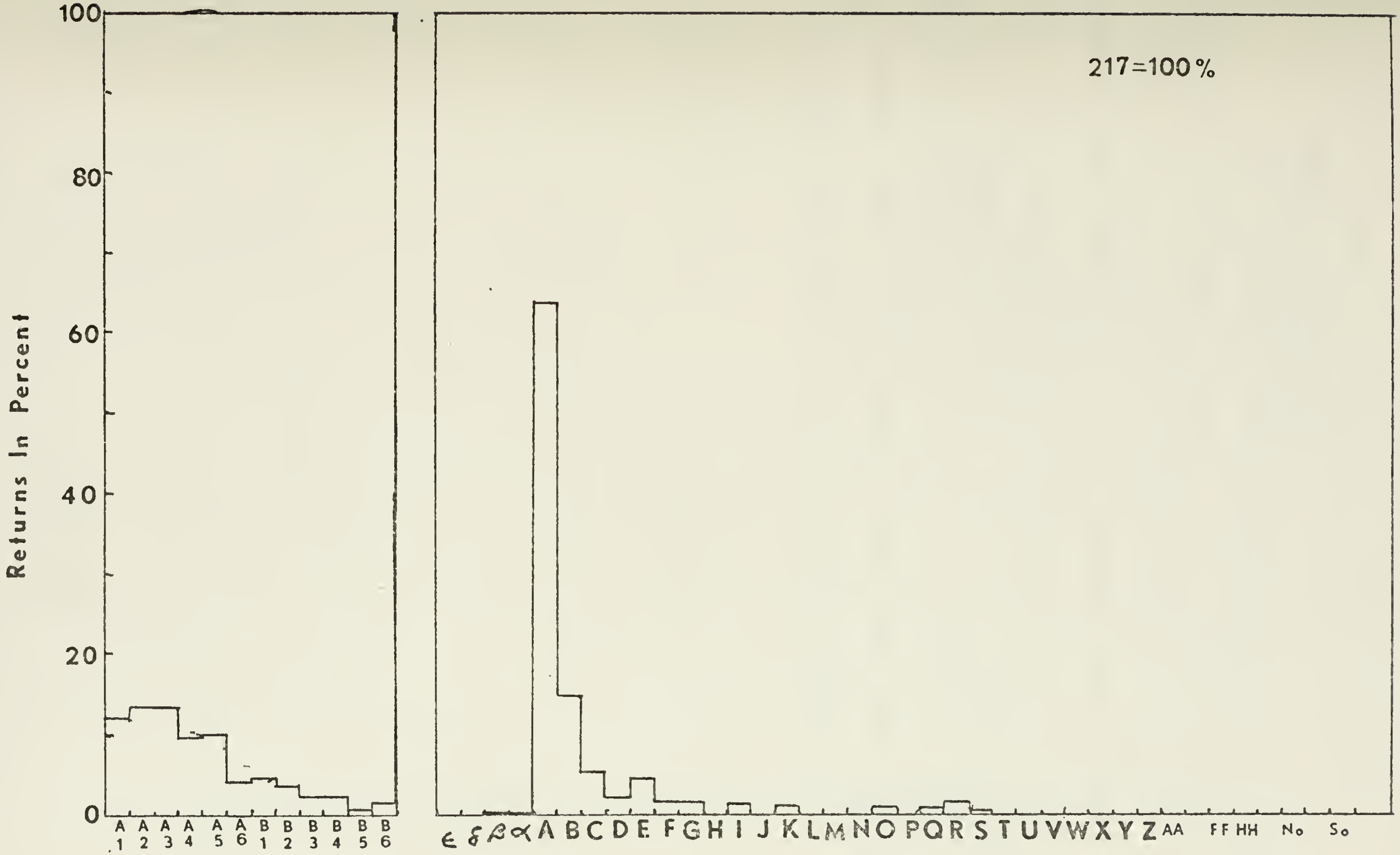

Figure 11. Distribution from Drop Point H (Overall)

Ano Nuevo Island and another went south to Morro Bay. One bottle from drop point S was found to the north of the bay at Tunitas Beach, 11 miles south of Half Moon Bay.

3. Returns by Drop Date

The individual station returns plotted by drop date are shown in Figures 12 and 13. On a number of drop dates the returns were very low for some drop points while being much higher from others. Drop points B and C (Figure 12) were most different from each other in terms of the trends of the returns and different from the other drop points. H, M, and S (Figure 13) generally were similar in their pattern of return rates. The seasonal trends that are roughly shown in Figure 6 may also be seen in Figures 12 and 13.

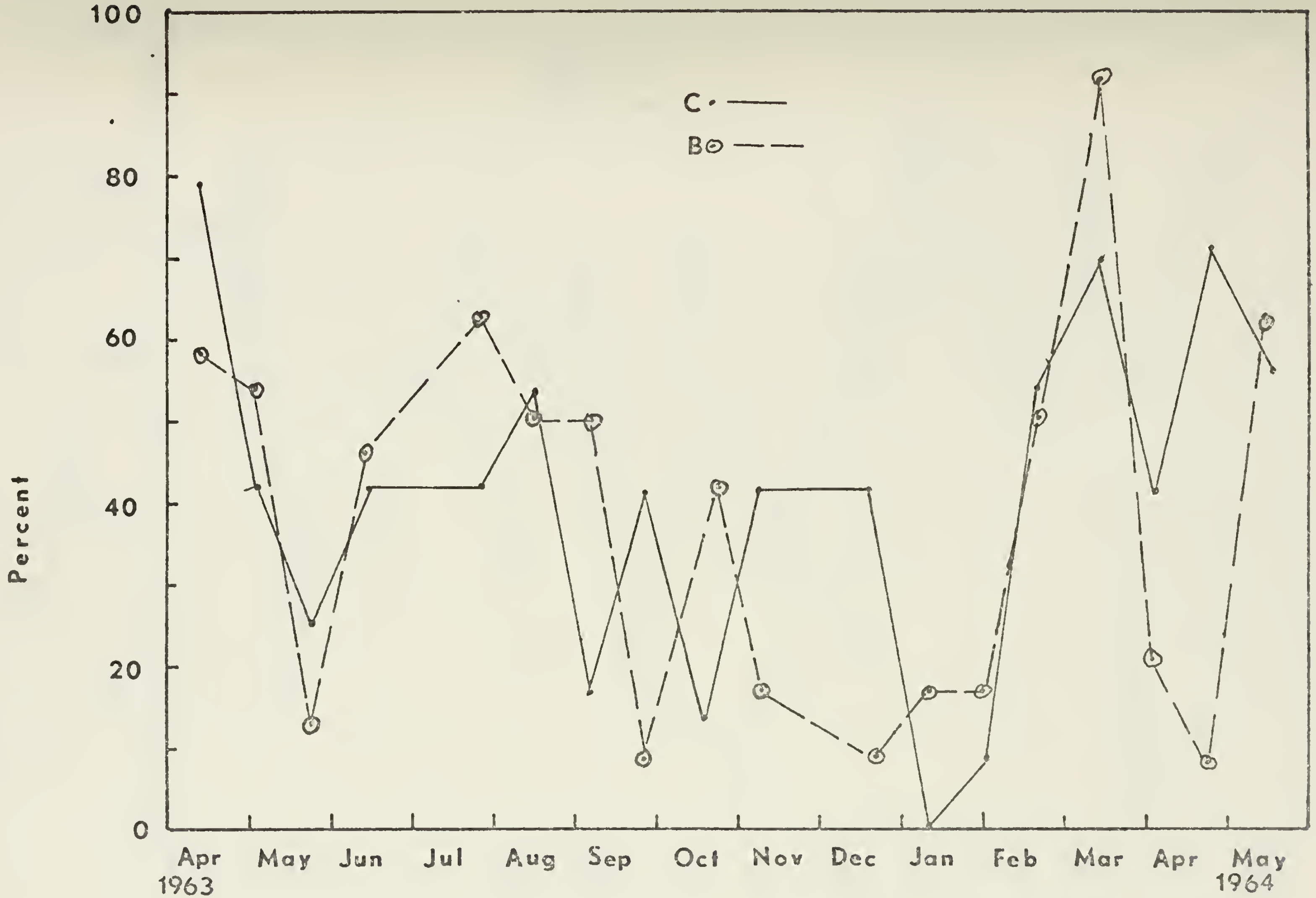

Figure 12. Bottle Returns versus Drop Date by Drop Point (B and C)

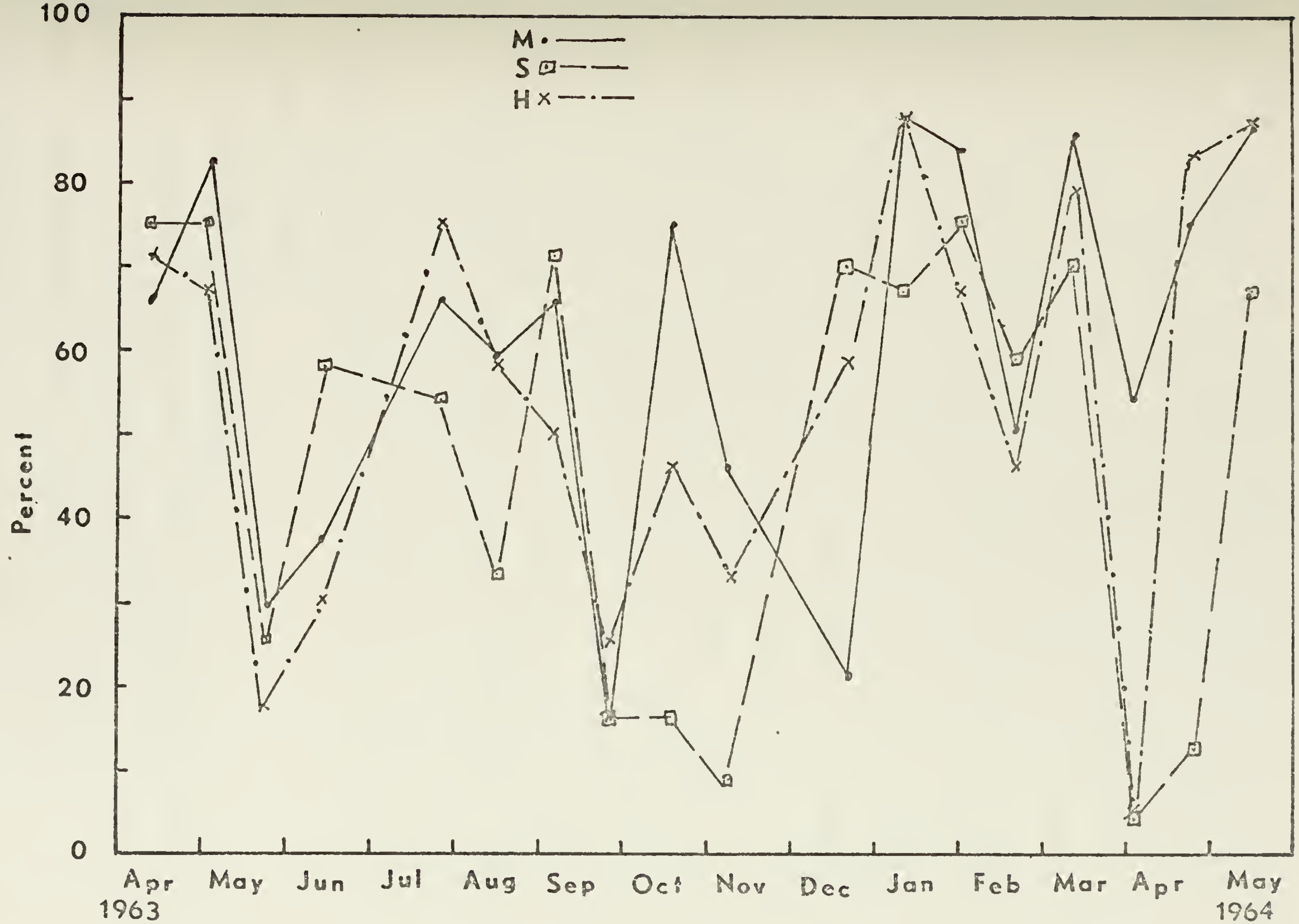

Figure 13. Bottle Returns versus Drop Date by Drop Point (S, M, H)

IV. CAUSES OF BOTTLE DRIFT

From examination of the drift bottle data, an attempt was made to determine the transporting agencies responsible for the drift. Four factors--ocean currents off the bay, winds, waves, and tides--were considered to be of possible importance. All of these mechanisms vary in time with different rates of change. Winds over the bay produce a transient movement of water which varies in speed and direction over short intervals of time in response to synoptic weather events passing over the bay. Waves, which are also dependent on synoptic weather events, tend to transport objects in the direction of wave travel which is usually toward the shore. Tides and ocean currents are more permanent features. Tidal currents repeat themselves over a 25-hour period so, although they would affect some of the drift bottle trajectories, their effect on the long-term circulation may be considered to be negligible. Ocean currents off the bay thus appear to be the most permanent of the important driving forces of the bay circulation.

A. OCEAN CURRENTS

1. Bay Circulation Model

Garcia (1971) developed a theoretical model of the circulation pattern of Monterey Bay using the shear flow of the ocean currents that occur off the bay as the sole driving mechanism.

The open coast circulation varies througout the year in a manner described by the three oceanic seasons, as discussed in the introduction. Accordingly, the bay circulation can be expected to respond seasonally as well.

From Garcia's shear-flow model, three circulation patterns are expected in the bay. They correspond with the direction of the oceanic current which changes with the seasons. During the Upwelling period and the Oceanic period, the offshore current flows southward along the coast. Collectively, these two periods are called the California Current season after the predominant offshore current in this season. During the Davidson Current season, the offshore current flows toward the north. The three models which reflect these current seasons are shown in Figures 14-16.

The southerly California Current would be expected to produce a counterclockwise circulation pattern in the bay. Either a single gyre (Figure 14) or a two-gyre pattern (Figure 15) appears probable. Because of the symmetry of the bay, the division between the two gyres would be expected to occur in the area of the Monterey Submarine Canyon. The northern gyre is probably flowing in the same direction as the southern gyre.

The circulation in the bay during the Oceanic period may be different from that occurring during the Upwelling period even though the offshore current direction is the same. The lack of upwelling during the Oceanic period and the associated decrease in the intensity of the northwest

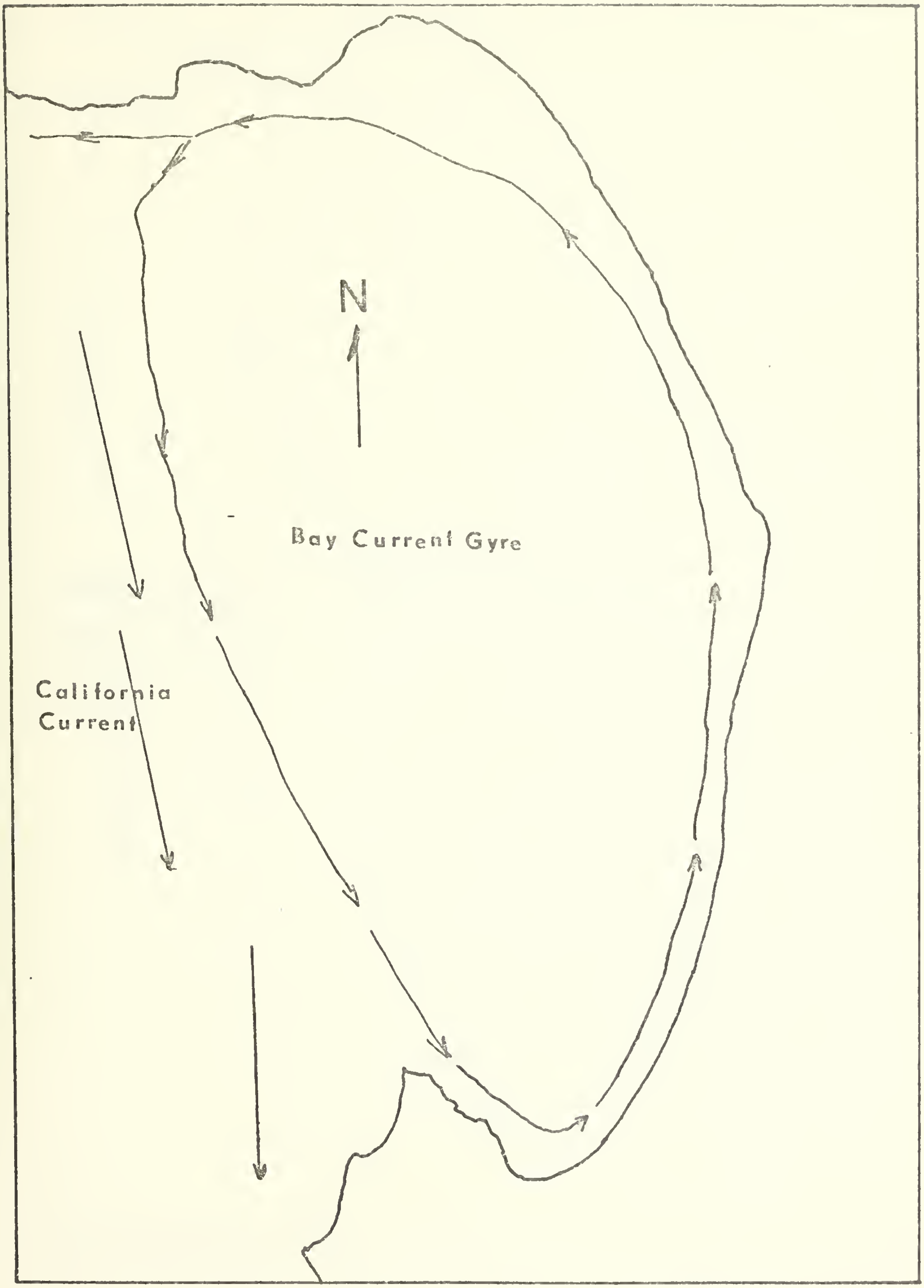

Figure 14. Single Gyre Circulation During the California Current Season (Garcia Model)

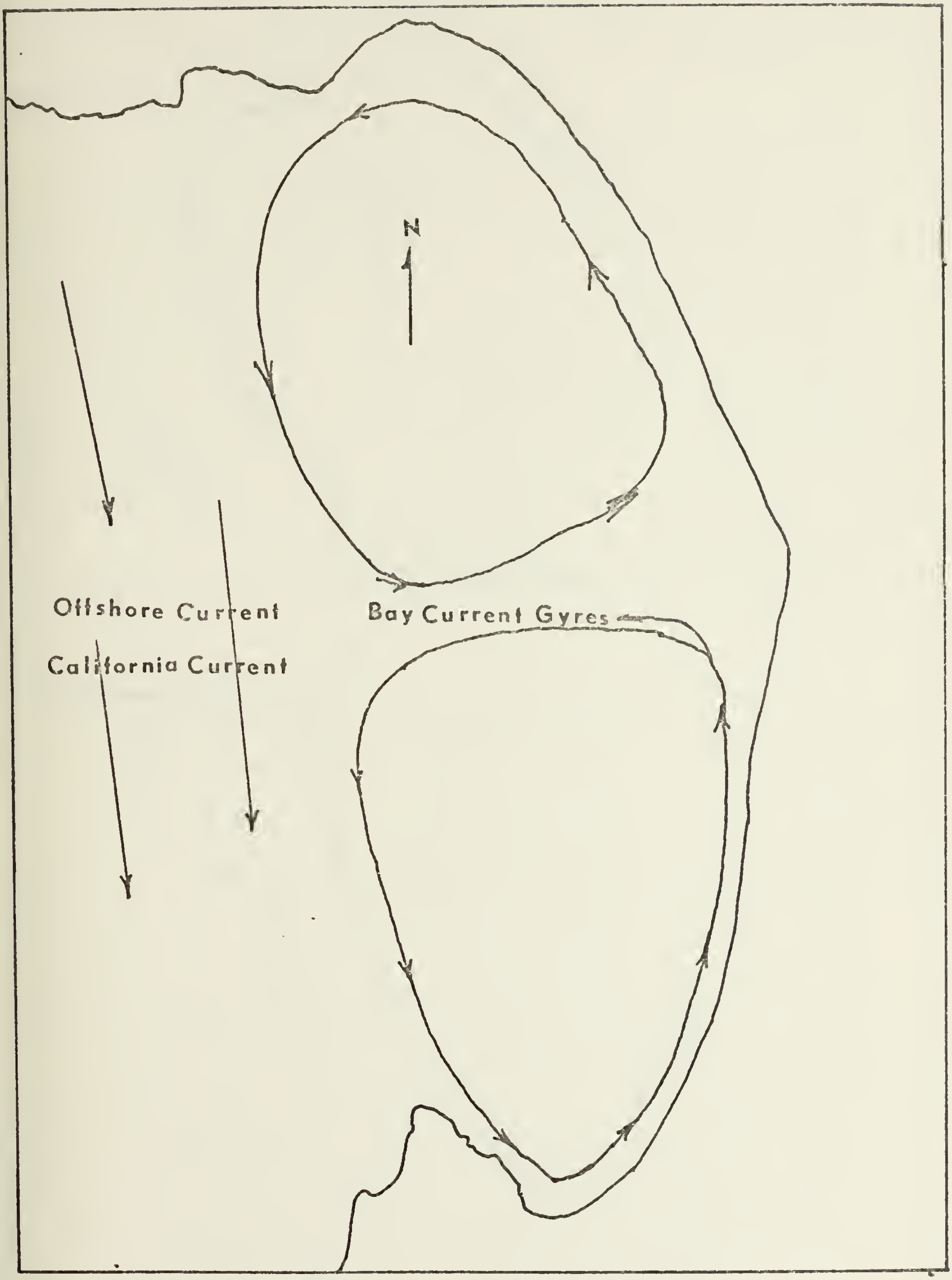

Figure 15. Two Gyre Circulation During the
California Current Season (Garcia Model)

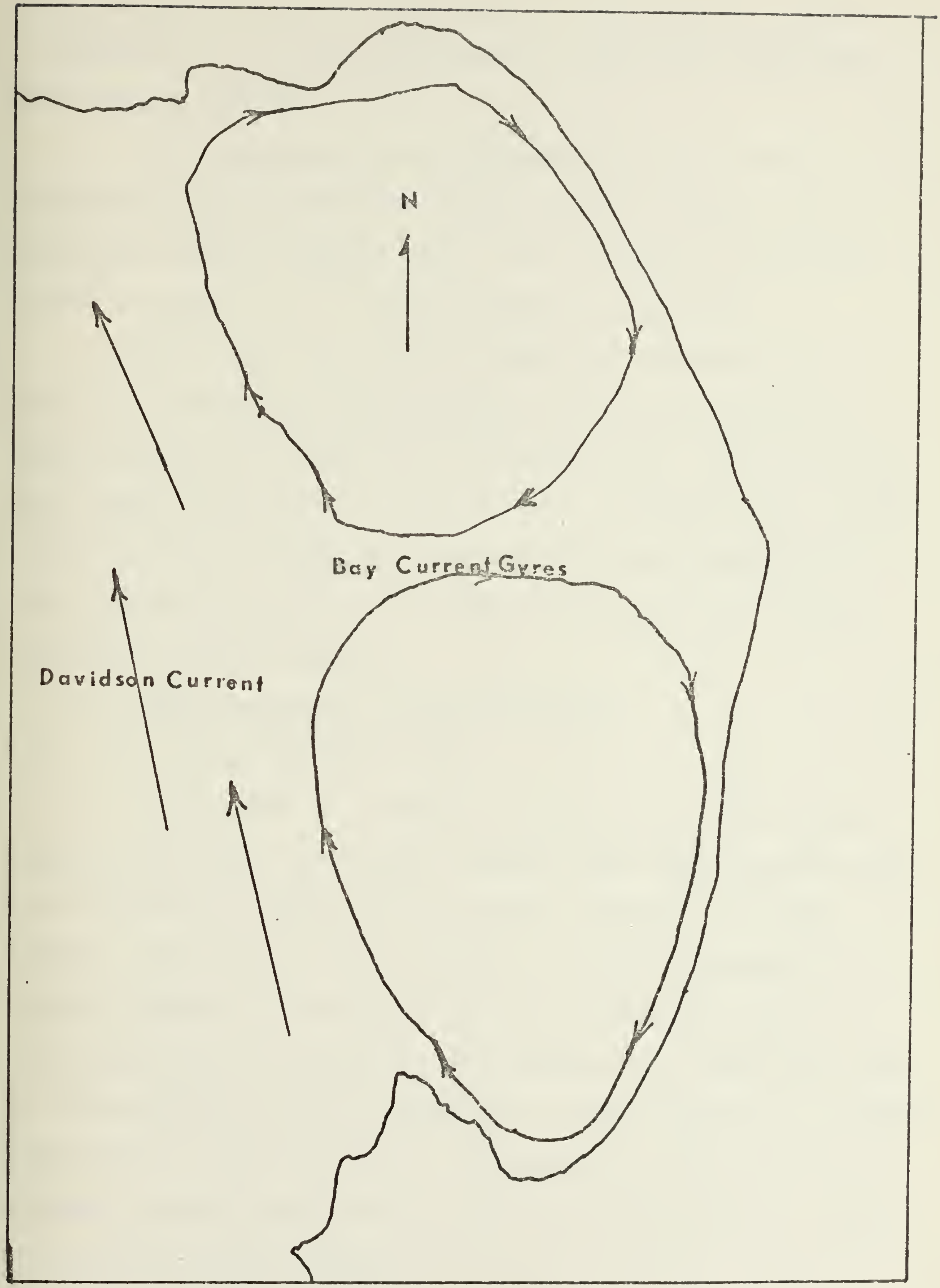

Figure 16. Circulation During the Davidson Current Season (Garcia Model)

winds along the Pacific coast may be important in causing a difference in the bay circulation between the Upwelling and Oceanic periods.

The northward flowing Davidson Current would be expected to cause the water in the bay to circulate in a clockwise pattern (Figure 16). For this time of the year either a single or a two-gyre pattern is expected.

These shear-flow driven models were adopted by the author as the most probably general circulation patterns expected to occur seasonally in Monterey Bay. These models were used as a guide in interpreting the drift bottle return patterns since it would be expected that the distribution and possibly the number of bottles recovered would reflect the model if it is valid.

2. Bottle Returns by Oceanic Seasons

a. Seasonal Divisions

In order to examine the variation with oceanic seasons the bottle drops were divided into three groups that are believed to represent the oceanic seasons. The drop numbers, drop date, and the number of bottles released per oceanic season are listed in Table 2. The time limits of the seasons were categorized according to the expected times of the seasons which are supported by the results of a CalCOFI drift-bottle study (Crowe and Schwartzlose, 1972) and a geostrophic current study (Wylie, 1966) for the period of time of the drift bottle survey.

TABLE II: BREAKDOWN OF THE OCEANIC SEASONS

Season	Time Period	Drop No.	Bottles Dropped
Upwelling	April to August 1963 March to May 1964	1-12, 28-35	240
Oceanic	September 5 to mid-November 1963	13-20	96
Davidson	mid-November 1963 to February 1964	21-27	84

b. Upwelling Period

During the Upwelling period returns were higher than the yearly average for each station. For drop points S, M, and H they are only slightly above the yearly average, but for B and C recovery rates were 8.5% and 10% higher than the yearly average.

The distribution of returns (Figures 17-21) is skewed to the north for all drop points. This is especially true for drop point S which had almost no bottles in sector A, a short distance to the south. Returns north of the north boundary of Fort Ord from all drop points were low, generally totalling less than 20% of the recoveries from any drop point during this period. The return rate from this area was even smaller for the three drop points closest to Del Monte Beach. There was a small secondary peak of returns in the Sunset Beach-Palm Beach area from station C. It is believed that this peak is related to the circulation and is not due to any bias as discussed under drift bottle limitations. Only a few bottles were found north of Sunset Beach in the bay.

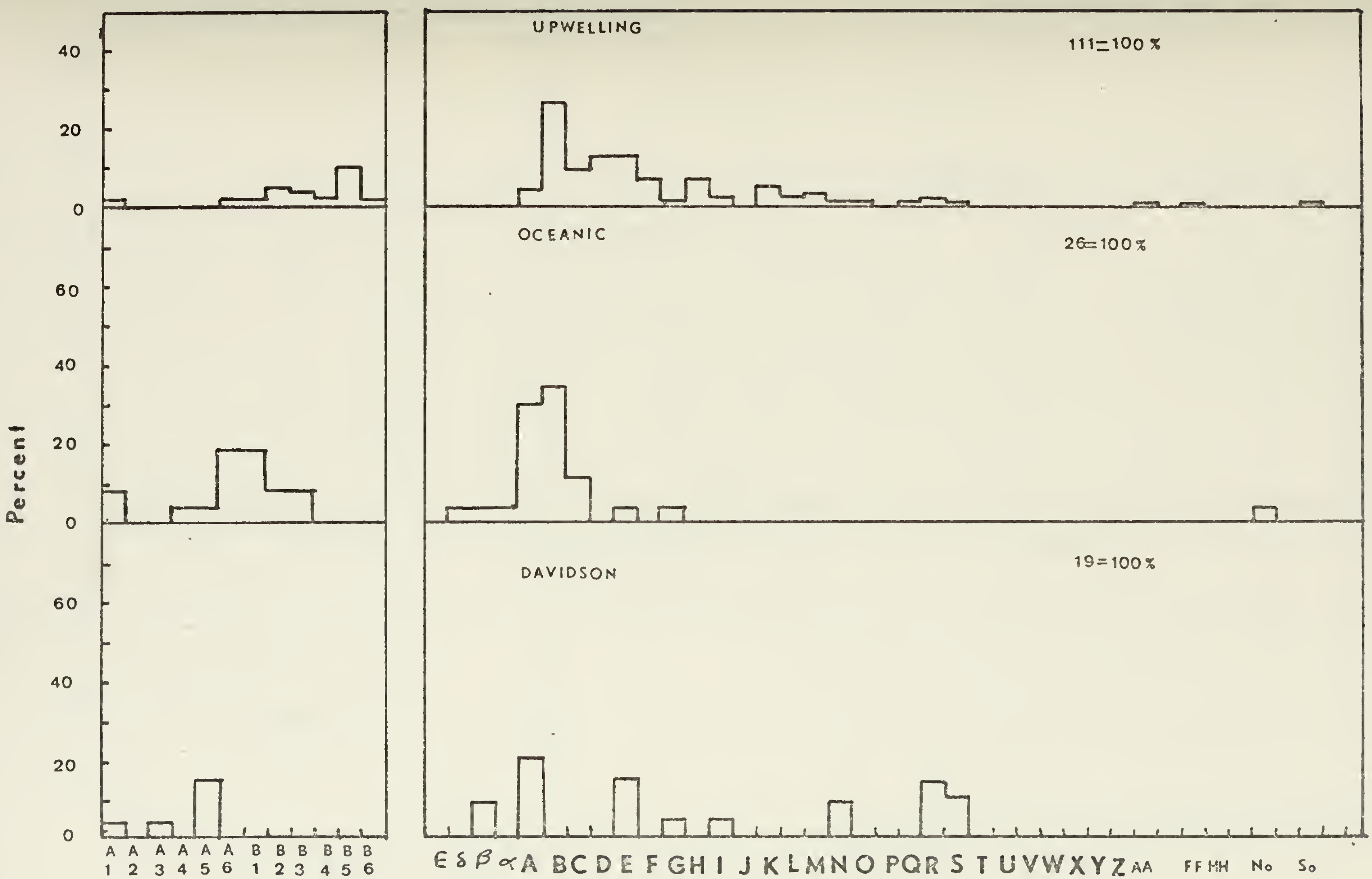

Figure 17. Bottle Returns by Oceanic Seasons: Station B

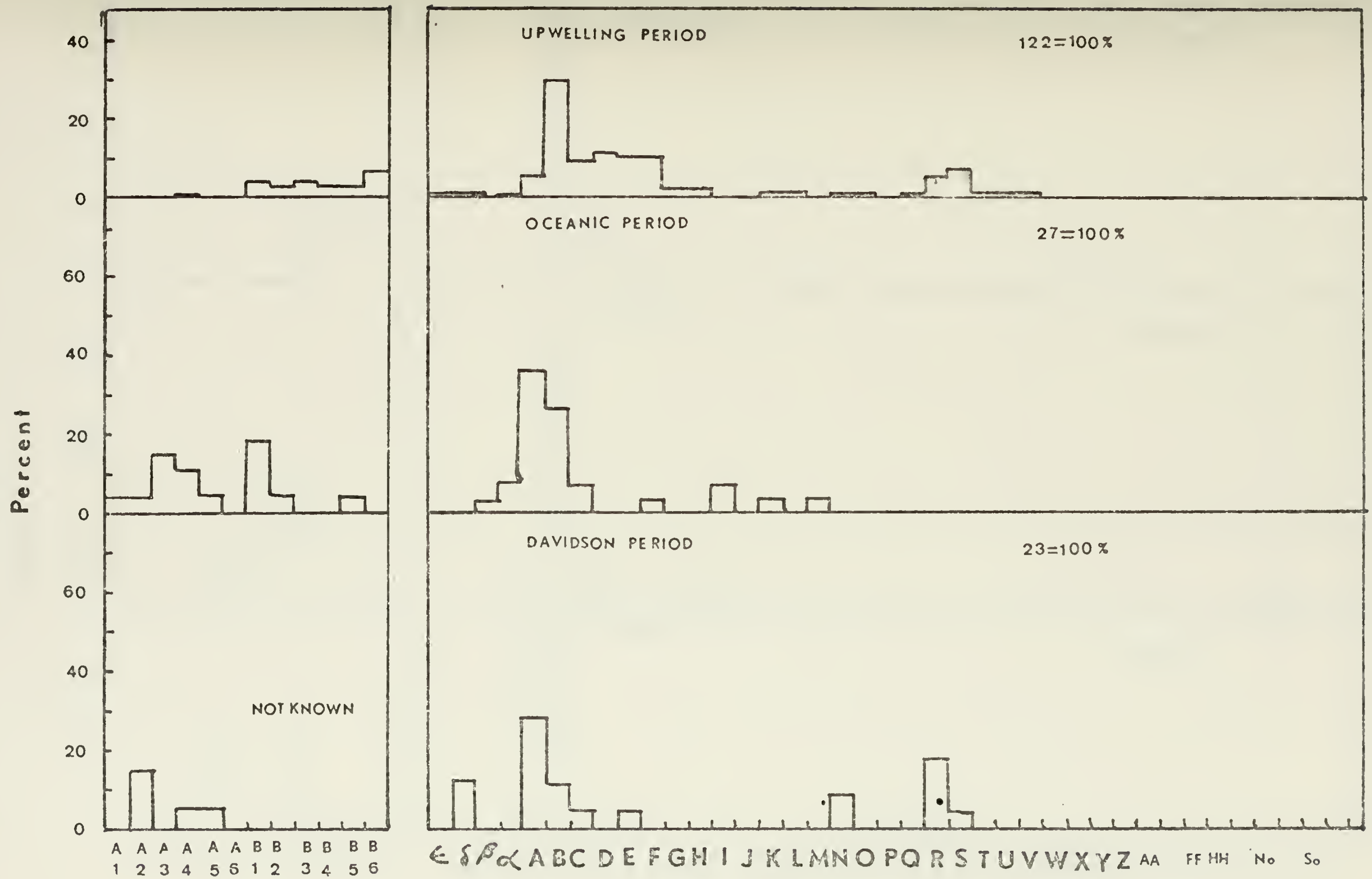

Figure 18. Bottle Returns by Oceanic Seasons: Station C

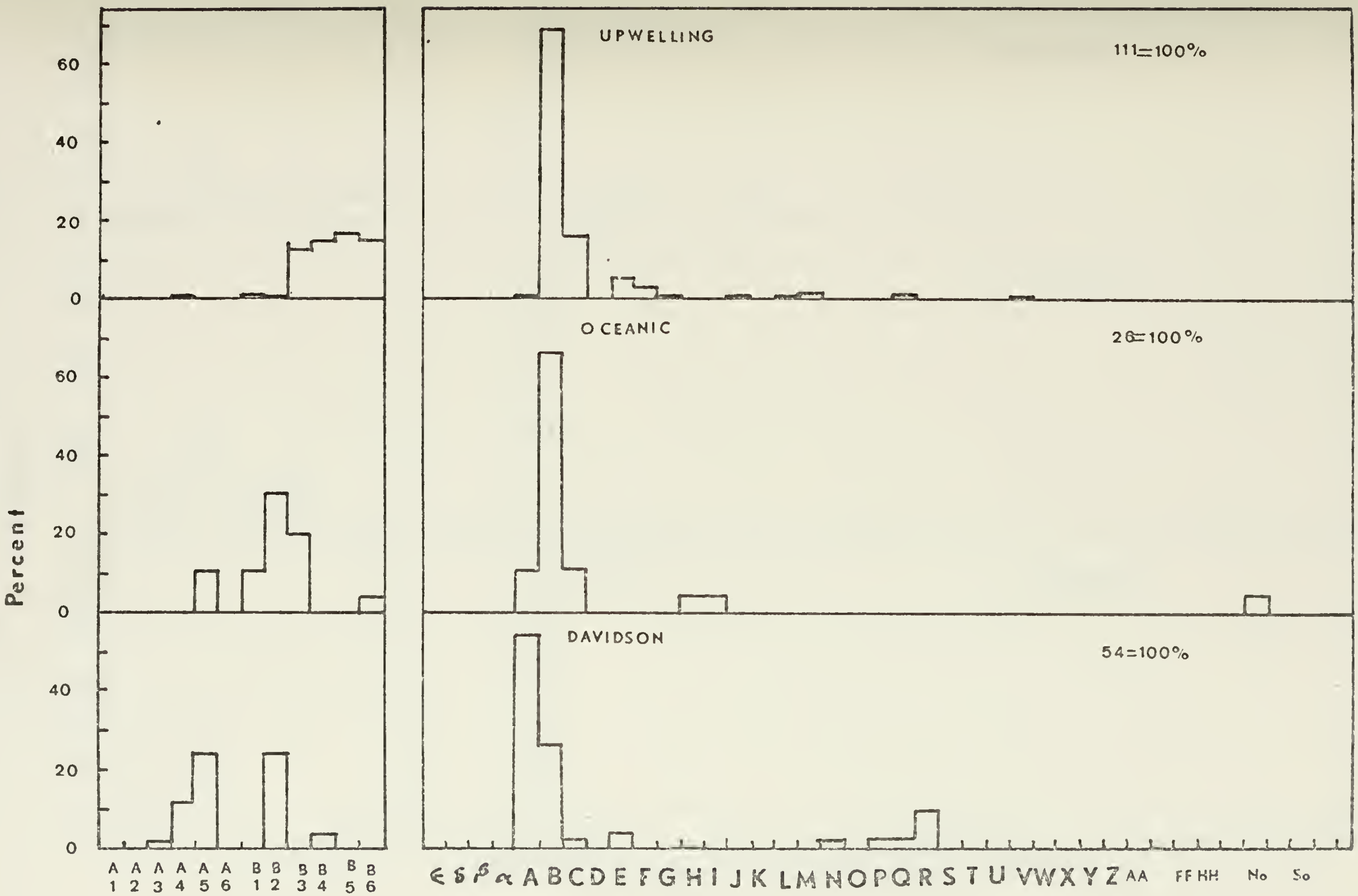

Figure 19. Bottle Returns by Oceanic Seasons: Station S

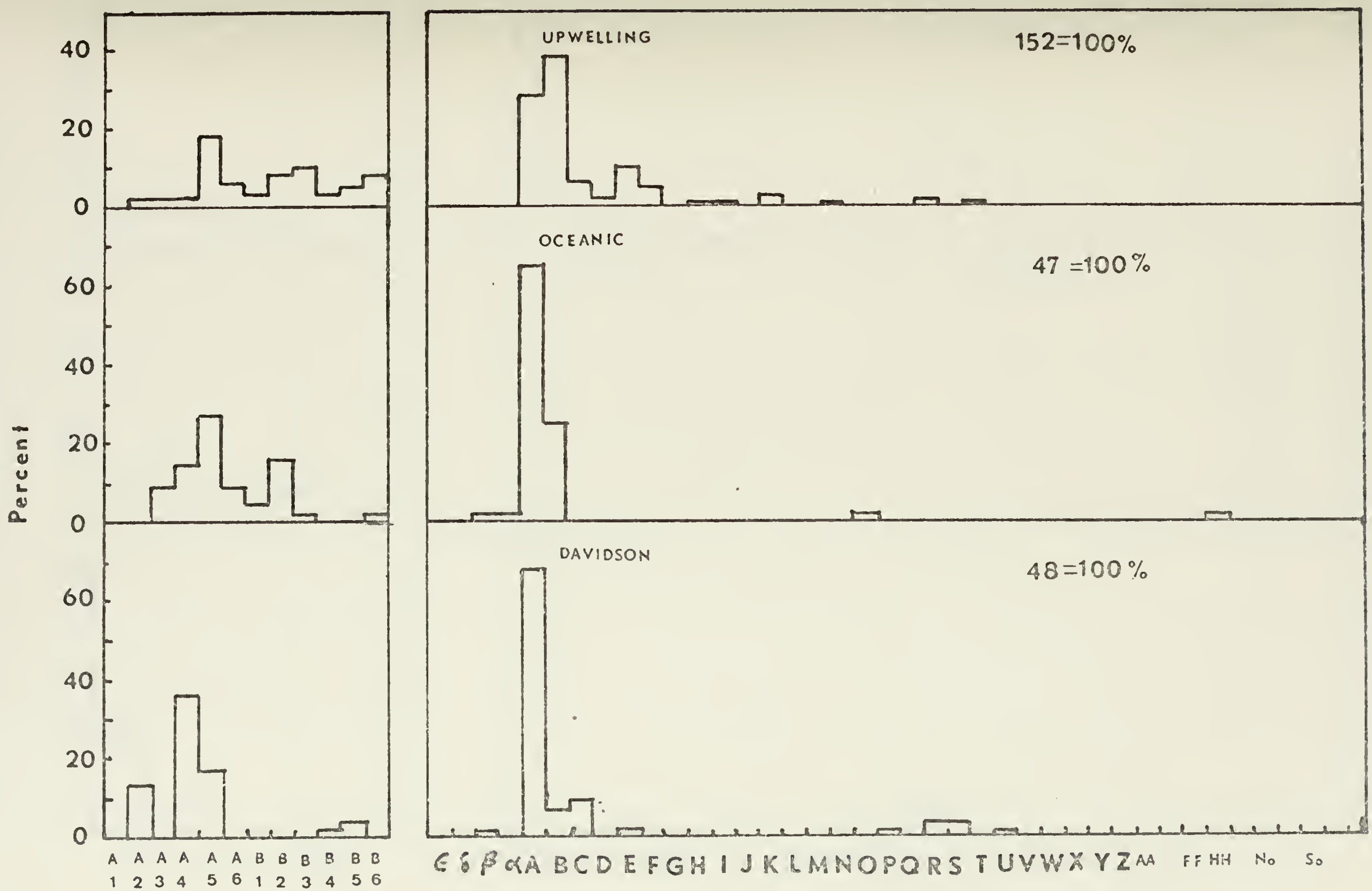

Figure 20. Bottle Returns by Oceanic Seasons: Station M

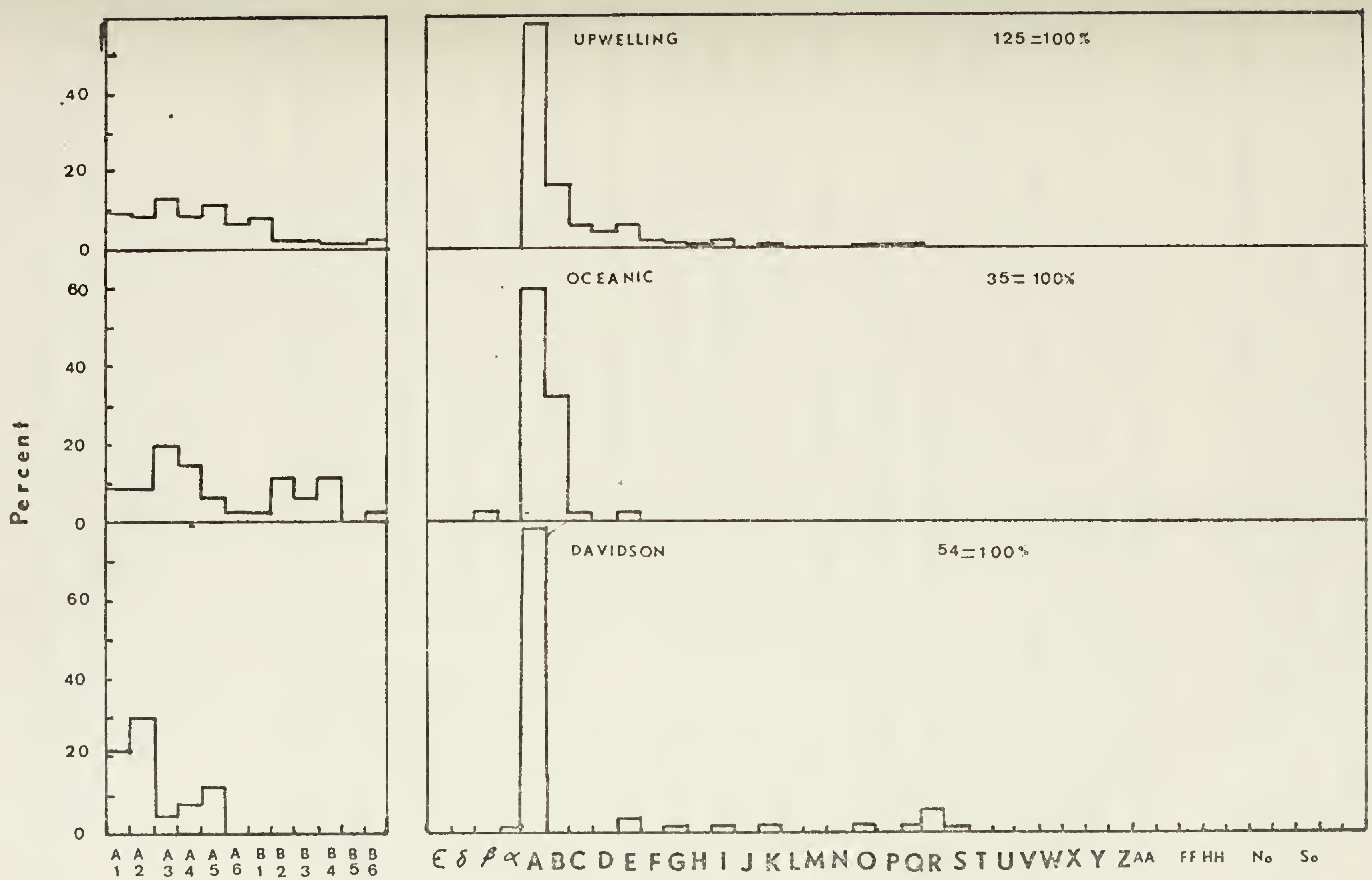

Figure 21. Bottle Returns by Oceanic Seasons: Station H

Almost no bottles were found along the north coast of the Monterey Peninsula. Even from drop point C, which is near Cannery Row, there was only one recovery. This is strong confirmation that the current along the north side of the peninsula is into the bay toward Del Monte Beach during this period.

No recoveries from outside the bay occurred for bottles from drop points S, M, and H during the Upwelling period. Two bottles from drop point C were found on the seaward side of the Monterey Peninsula south of Point Pinos. A bottle from drop point B was found to the south at Morro Bay.

The drift bottle results for the Upwelling Period appear to indicate an easterly current along the northern shore of the Monterey Peninsula. The current turns northward and flows upcoast offshore from Del Monte Beach. The secondary peak of returns from Station C near sectors R and S may suggest that there is a separate circulation in the northern bay. The circulation along the coast looks similar to that predicted by Garcia's model if it is extended to the nearshore regions. The model predicts a counterclockwise gyre or two counterclockwise gyres when a southerly current flows offshore as occurs during the Upwelling period. The possible separate circulation in the northern bay may be the second gyre in the northern bay.

c. Oceanic Period

During the Oceanic period, all drops showed a recovery rate which was lower than the yearly average for each station. The returns from B, C, and S were very low

at 29.2%, 28.2%, and 28.2%, respectively, while the return from drop point H was somewhat higher at 37.5%. The return from M was 51.0%, which is 9% lower than the yearly average of 60.0%. The sample size during the Oceanic period was small since both the number of bottles dropped and the return rate were small.

The distribution of returns, as shown in Figures 17-21, shifted slightly to the south for all drop points compared with the Upwelling period. Although the returns similarly extended upcoast or to the north from the drop points, the bottles were distributed over a much narrower area of coast than in the Upwelling period and were recovered closer to the drop points. For example, for drop point M, about 90% of the recoveries were in sectors A and B during the Oceanic period, while only 70% were recovered in these sectors during the Upwelling period. Only a few bottles were returned from north of Fort Ord. No secondary peak was observed in the vicinity of Sunset Beach during the Oceanic period.

Bottle returns to the west of Wharf No. 2 were low, but larger in this area than during the rest of the year. Drop point C, with the highest return in this area, had only 11% of its recoveries from the Cannery Row sector even though it is located just offshore.

No bottles left the bay from drop points C, H, and M, although one was found at the northwestern limit of the bay at Natural Bridges State Beach. One bottle moved northward from drop point S to Pigeon Point north of Point Ano Nuevo and another moved northward from drop point B to

Tunitas Beach eleven miles south of Half Moon Bay. A bottle from drop point B was also found at Point Joe on the seaward side of the Monterey Peninsula.

The drift bottle results from the Oceanic period suggest that the current in the southern bay is in the same direction as during the Upwelling period, but that the circulation is weaker. The bottle drift in the southern bay suggests a counterclockwise current pattern along the shore which may be similar to that predicted by Garcia's shear-flow model for this area. The returns from the northern bay were too few to indicate whether or not a separate current gyre exists there. The returns to the north of the bay suggest that the Davidson Current may have been present part of the time.

d. Davidson Period

Drop points B and C showed very low recovery rates of 28.6% and 23.8%, respectively, compared with the yearly returns, while the return from M was slightly less at 57.1%. The highest recovery rates for the year were reached for stations H and S, with 64.3% and 66.7%, respectively.

The distribution of bottle returns (Figures 17-21) was shifted further to the south than during either of the other two oceanic seasons. This shift is especially evident for drop point S from which there were almost no recoveries in sector A during the Upwelling period. During the Davidson period, 54% of the bottle returns from S were in sector A indicating a strong shift to the south from this station. There were almost no bottles found between the southern

boundary of Fort Ord and Moss Landing. In the area of Sunset and Palm Beaches all five drop stations showed a secondary peak of returns. This peak in sectors R and S is particularly pronounced for drop points B and C, from both of which 20% of the total returns from these stations came.

Returns from the bay to the west of Wharf No. 2 were very low during the Davidson period and about equal in percent to the returns in this area during the Oceanic period. No bottles drifted out of the bay to areas further north. Three bottles from drop point C were found south of the bay and these were picked up on the Monterey Peninsula.

The drift bottle results indicate a southward movement from drop points other than C. Bottles from drop point C moved in what appeared to be a relatively direct path to sectors A and B contrary to how they would be expected to move from Garcia's model.

The drift bottle results from the Davidson period appear to fit Garcia's ocean current shear model (Figure 16) as a description of the movement along the coast of the drift bottles although the bottles from station C show only a small effect of the ocean component of the current. A clockwise current pattern with a southerly current along the coast off Del Monte Beach which turns west and flows along the north shore of the Monterey Peninsula appears to exist. The secondary peak of bottle returns observed in the northern bay for all drop points coupled with low returns for several miles to the south of this peak seems to suggest a two-gyre model with one gyre in the northern bay and the other in the southern bay.

During the Davidson period, the surface circulation appears to be contained within the bay since so few bottles left the bay and those that did were only transported as far as the seaward side of the peninsula. Also supporting the view of a relatively closed circulation is the fact that no bottles were found to the north of the bay even though the predominant direction of the offshore current is northward.

B. WIND

Wind is one of the major driving forces of surface currents so it is logical to consider it as a factor in drift bottle movement.

The seasonal wind regime on the California coast, including the Monterey Bay area, is reflected in the seasonal offshore current patterns which have effectively been accounted for in the previous section. When considered on a short-term basis, the winds blowing over Monterey Bay are variable in speed and direction in response to the changing synoptic weather conditions and to the local sea-land breeze circulation in the vicinity of the coast. These local winds create wind-driven currents in the bay of a relatively transient nature. It is to the latter that the following discussion is directed.

The dominant wind direction in Monterey Bay, as on most of the California coast, is northwest. This may be attributed in large part to the presence of the quasi-permanent subtropical high pressure cell that is centered off the California coast. In addition, a diurnal pattern of onshore-offshore winds is present along the coast during most of the year. The stronger

afternoon seabreeze component is characteristically from the northwest while the low wind speeds found at night and in the early morning are usually offshore.

From examination of Figure 2, it may be seen that drift bottles released at the five drop stations would be expected to drift toward sectors A and B on Del Monte Beach under the prevailing northwest wind. The fact that the largest portion of the bottles were found in sectors A and B clearly indicates the important influence of the winds in moving the surface water in the southern part of the bay.

An attempt was made to examine the drift bottle direction with respect to the wind direction. In order to get an estimate of what should be expected, the Ekman wind-drift model was compared with the drift bottle results.

The Ekman wind-drift model predicts that in the absence of a coastal barrier, a bottle at the surface will move in a direction 45 degrees to the right of the wind in deep water in the northern hemisphere. As the water gets shallower, the angle diminishes until for shallow depths the water moves in the direction of the wind. The water depth is actually a relative depth governed by the wind speed, so that as the wind speed increases the relative depth becomes smaller (Neumann, 1968).

To investigate the deviation of bottle drift from the wind, those bottle returns where the drift interval appeared to represent the actual period of time the bottle was afloat were chosen. Only bottles recovered in less than four days were considered. The net direction of bottle drift was taken

as the direction of a line drawn from the drop station to the bottle recovery point on the shore.

Hourly wind observations for the period of study were available from weather records of the Naval Auxiliary Landing Field (NALF) in Monterey and are considered to be reasonably representative of the winds in the area of the drop points. There were also some wind measurements made near the drop area by the people conducting this survey. The direction of the NALF wind measurements compared well with these field measurements, but the speeds indicated by the NALF data were generally several knots less than those from the field measurements.

For a given drop date the observed hourly winds were plotted in the form of a vector diagram such as is shown in Figure 22. The net wind direction was obtained from the line drawn from the drop time to the pick up time. The lengths of the vectors plotted were proportional to the square of the wind velocity since this is the manner in which the wind stress on the water is observed to vary. In general, the wind velocities were considered only for their effects in changing the direction of drift and were not used to compute the drift speed.

The angle between the bottle drift direction and the net wind direction over the bottle drift interval was determined for 418 bottles. Careful examination of the data showed that bottle drift significantly to the left of the wind (by as much as 80 to 100 degrees) was associated with a northwest wind direction and that for other wind directions bottle drift

was generally approximated by the Ekman model. Figure 23 shows the distribution of bottle drift angle with respect to the wind direction.

For the case of bottles drifting under the influence of wind directions other than from the northwest, almost all of the bottles are found at angles less than 45 degrees to the right of the wind, with 10° to 20° to the right of the wind being most common. This distribution of angular deviation from the wind direction is generally what is predicted by the Ekman wind drift model in shallow water.

For bottles drifting under the influence of northwest winds, a strikingly different pattern is observed. Figure 23 shows that the bottle distribution is strongly to the left of the wind. It is hypothesized that a northwest wind induces a strengthening of the northward longshore flow in the extreme southern end of the bay, as shown in Figure 24.

In three cases where the bottles appeared to have been recovered immediately after reaching the beach and the wind velocity remained constant, the Ekman drift speed and the speed computed for the drift bottles were compared. The drift bottle speeds were found to be within a few centimeters per second of those calculated using the Ekman model.

The components of the bay currents caused by winds and by the offshore currents may act to reinforce or oppose each other. Reinforcement appears to occur frequently in the southern bay for northwest winds during the months when the California Current flows along the outer coast. On the other hand, the observation noted earlier that during the Davidson

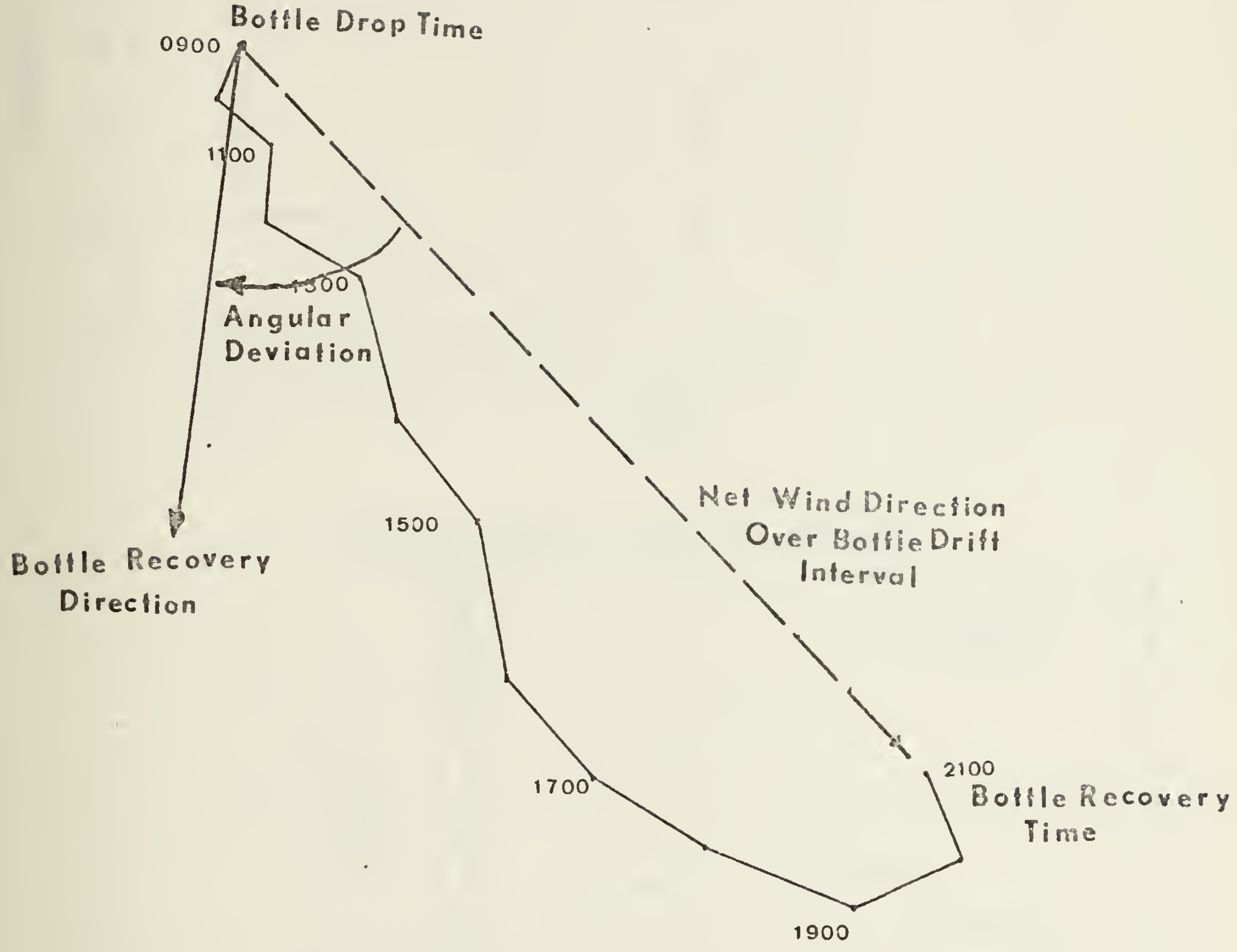

Figure 22. Determination of Bottle Drift with Respect to Net Wind Direction

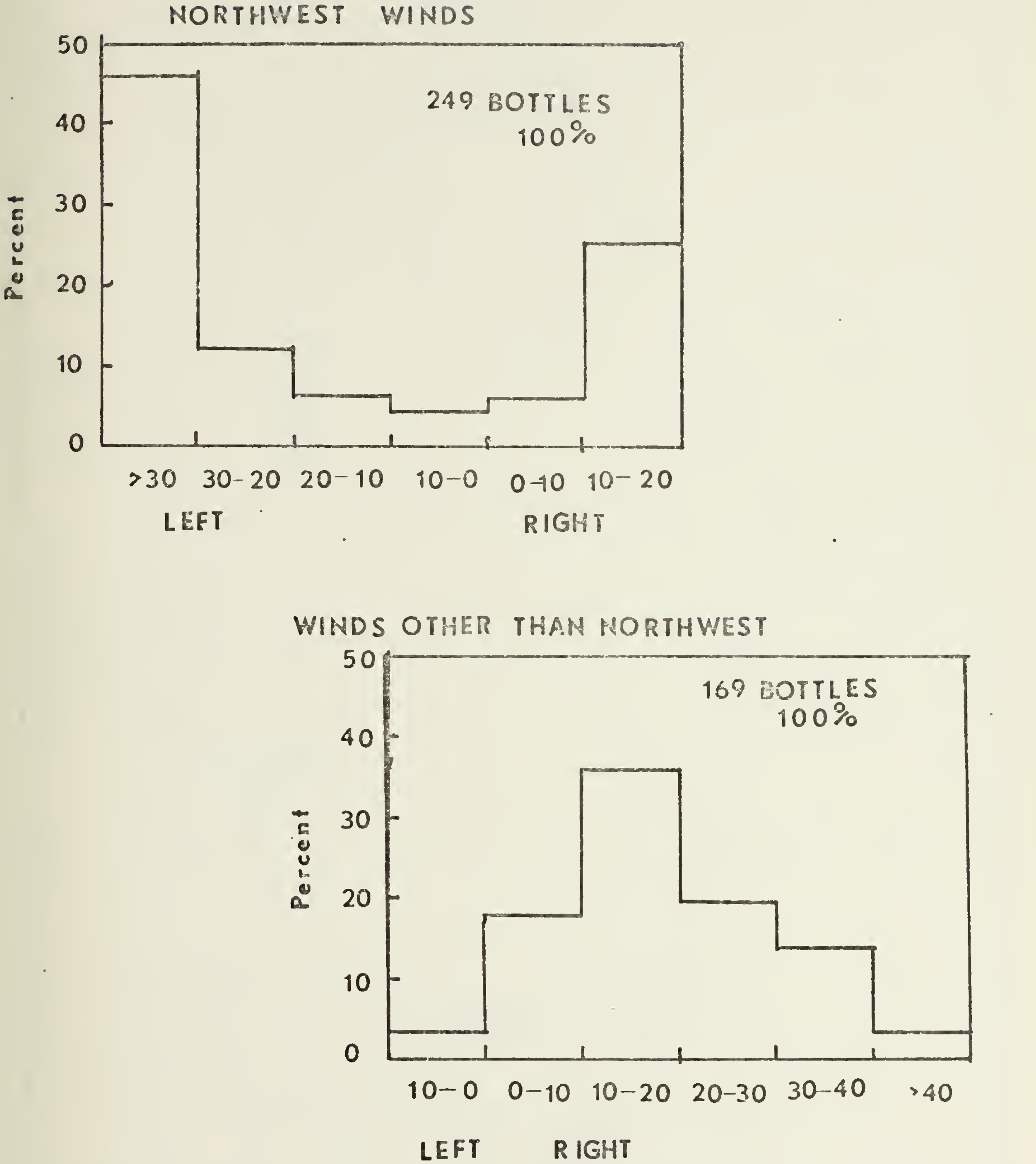

Figure 23. Bottle Drift Angle with Respect to Wind Direction

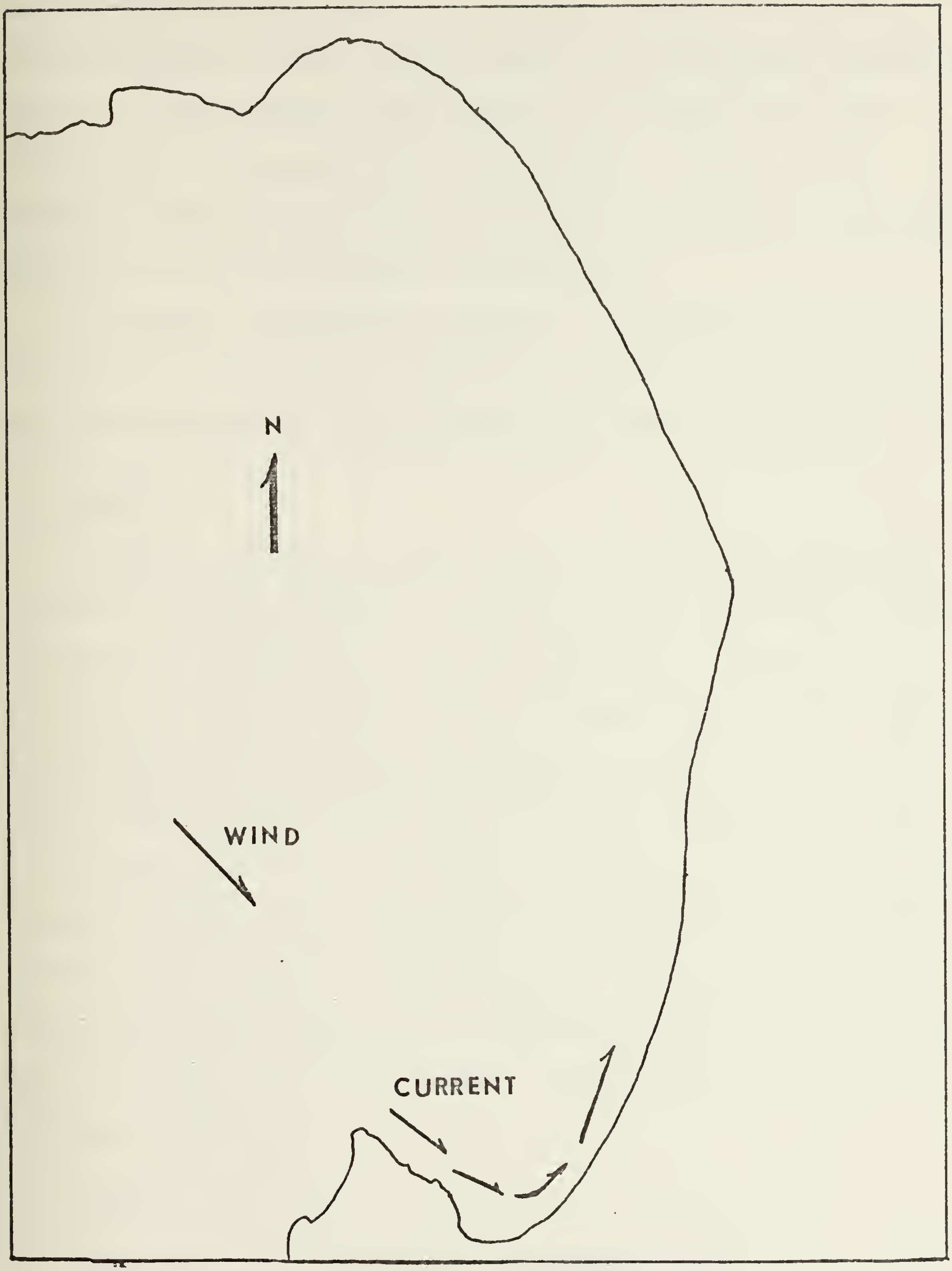

Figure 24. Circulation Generated by Northwest Winds

period bottles from drop point C moved preferentially toward coastal sectors A and B rather than in the direction predicted from the ocean current model appears to indicate that the wind effects dominated over ocean current effects. This further suggests that winds are the primary cause of transient surface currents in southern Monterey Bay.

In summary, although the effect of the Garcia-type model is evident, the apparent direction of bottle movement in the bay is determined by the wind direction much of the time.

C. WAVES

The mass transport of water by swell is negligible when compared to that produced by wind waves and therefore is not considered a significant factor in moving the surface water. Even in the case of wind waves, it appears from Stokes third-order theory that the surface transport due to waves is less than a tenth of that produced by the wind (Wiegel, 1964, pp. 324). Accordingly, since wind waves are caused by the wind, the mass transport due to wind waves may be considered a part of the wind-driven transport. It is therefore considered that winds alone effectively represent the combined effects of waves and wind in moving the surface water. Wave effects will not be examined further.

D. TIDES

Tides can be an important current-causing force in coastal waters. Tides in Monterey Bay, as for most of the Pacific coast of the United States, are of the semi-diurnal mixed type. This complicated pattern of tides leads to a rather complicated

pattern of tidal currents. Tidal currents on the open continental shelf in the northern hemisphere are rotary, turning clockwise and completing a cycle every 12.4 hours. Because of the inequality of the tide heights and times, the two tidal current cycles per day differ in their speeds and their rate of change of direction. However, from one day to the next, the diurnal pattern approximately repeats itself so that little net transport of water occurs. Tidal currents of this character occur off the entrance of San Francisco Bay and it is probable that a similar tidal current pattern exists in Monterey Bay.

No successful attempt at measuring the tidal currents over the broad shelves of Monterey Bay has been made, although tidal currents with velocities of up to 50 cm/sec have been observed in the Monterey Submarine Canyon (McKain and Broenkow, 1972). <u>Tidal Current Tables 1973</u> for the Pacific Coast of North America and Asia describes the tidal currents in the bay as weak and variable. Lazanoff (1971), in an unsuccessful attempt to verify Hansen's hydrodynamical-numerical model for Monterey Bay, concluded from his examination of current data that he could make no direct statement about tidal current velocities and directions, but suggested that the currents are probably less than 0.1 knot.

Because knowledge of the movement of individual bottles is incomplete, drift bottles provide a poor method for trying to examine the effects of tidal currents. However, at times of calm weather and relatively large tide ranges, such effects might be reflected in the number of bottles recovered or in

their distribution along the coast. An attempt was therefore made to look for tidal current effects in the drift bottle data at times of low wind and large tide range for bottles returned in less than 25 hours, but without success.

From the above considerations, it appears that tidal currents are not an important factor in net long-term movement of the water in Monterey Bay, and have a negligible effect on average flow due to their rotary nature.

V. MORNING-AFTERNOON DROP DIFFERENCES

Earlier it was stated that there was a significant difference between the number of returns from morning and afternoon drops. In this section, the differences in the distribution and the rate of returns from morning and afternoon drops from the five stations for the three oceanic seasons will be examined. The data for each drop point by oceanic season are presented in Appendix E.

For all drops during all of three seasons, with two exceptions, the recovery rate for morning drops was higher than for the afternoon drops. The exceptions are drop point B for the Upwelling period and drop point S during the Oceanic period. The cause of these exceptions is not known.

Figures 25 through 29 show that during the Upwelling period all stations except C show a much more peaked distribution for the morning drop returns than for the afternoon drops. The returns for the afternoon drops show a much more pronounced dispersal to the north than those for morning drops. For drop point B the returns exceeded 50% in sector B for the morning drops while no one sector contained over 15% for the afternoon drops. Over 90% of the morning drop returns for this station occurred in sectors A through F while those for the afternoon drops were more widely dispersed along the coast. Drop point H shows a strong difference between morning and afternoon drops, with 78% of the returns in sector A for

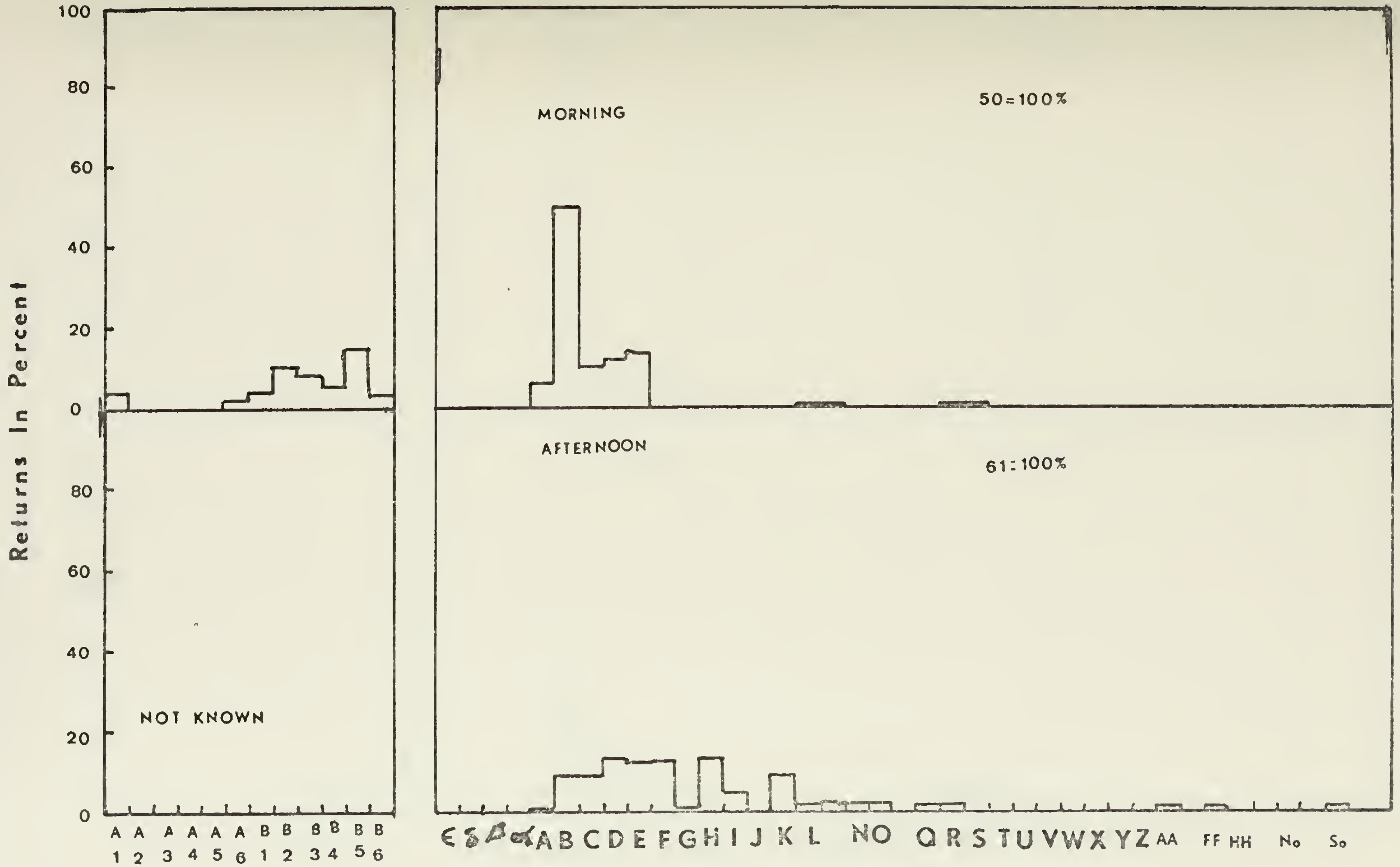

Figure 25. Morning versus Afternoon Differences During Upwelling Period: Drop Point B

Figure 26. Morning versus Afternoon Differences During Upwelling Period: Drop Point C

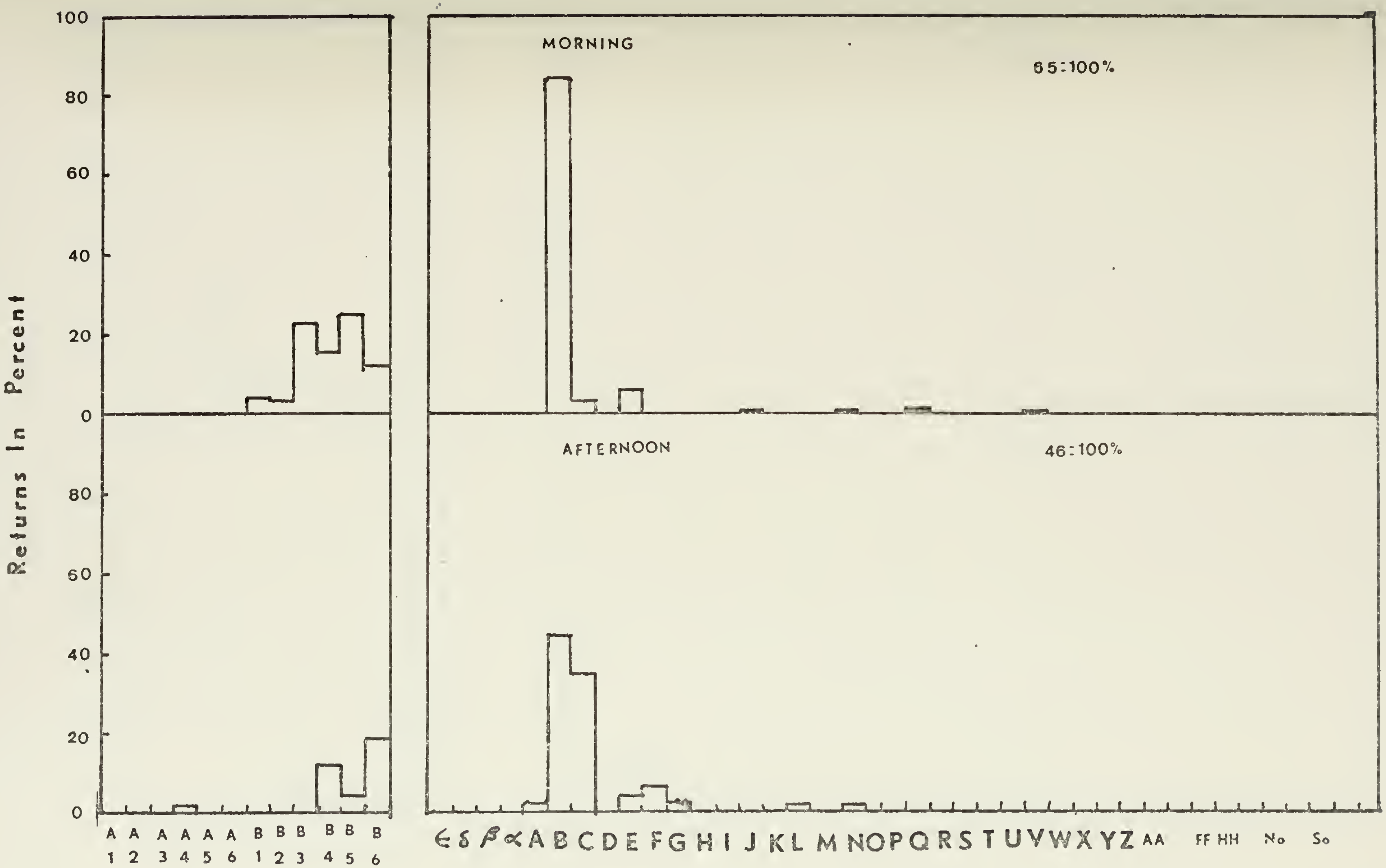

Figure 27. Morning versus Afternoon Differences During Upwelling Period: Drop Point S

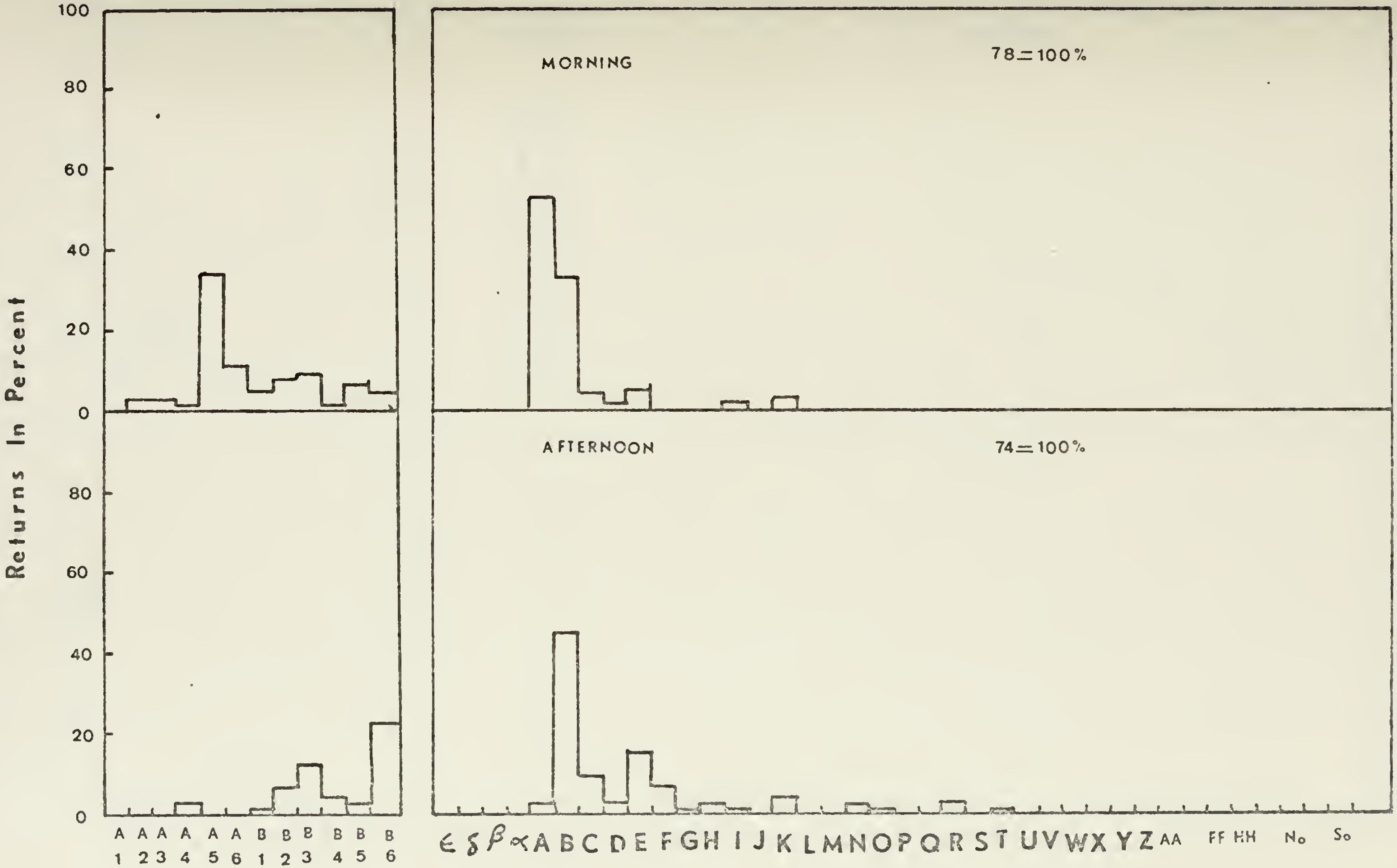

Figure 28. Morning versus Afternoon Differences During Upwelling Period: Drop Point M

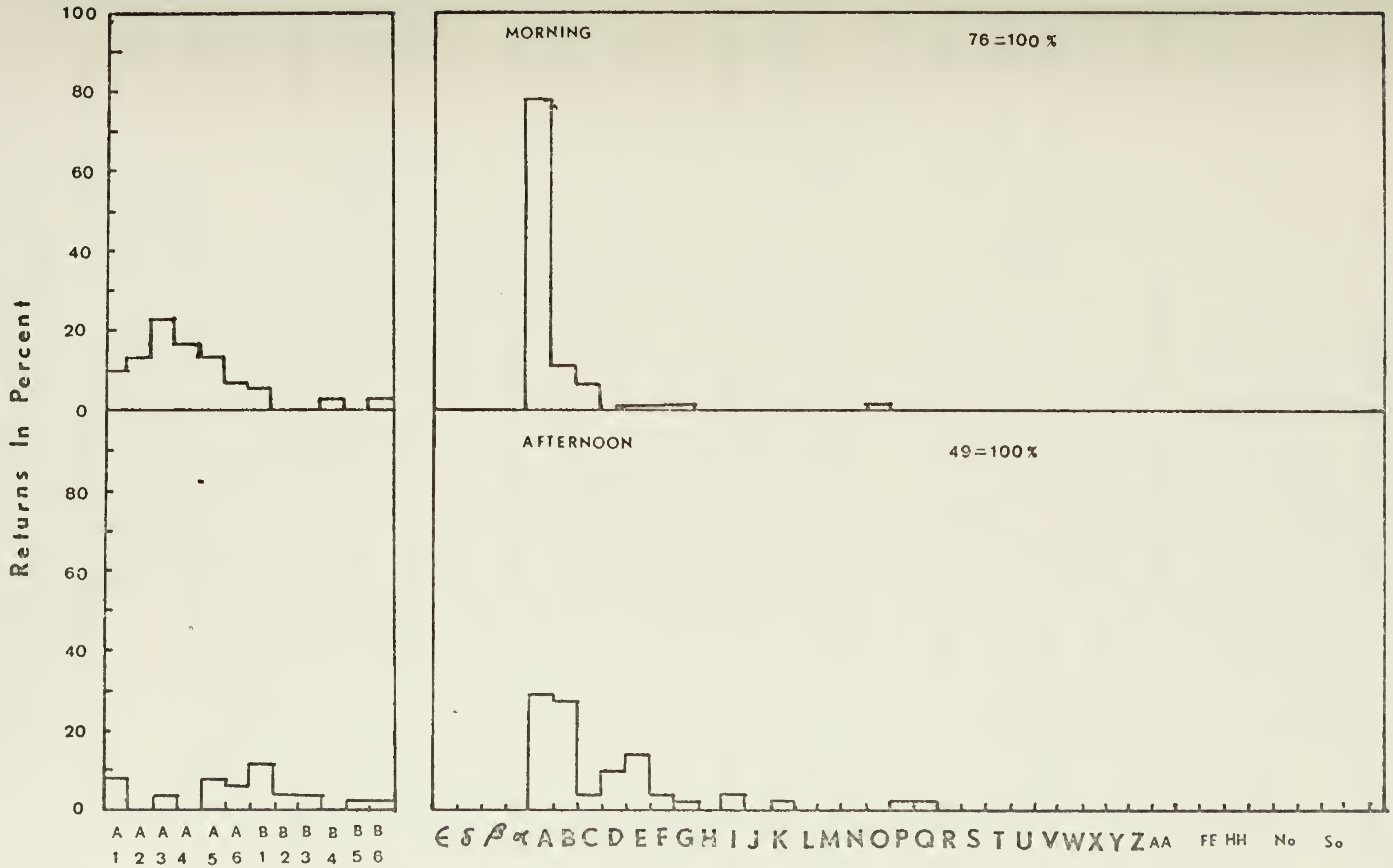

Figure 29. Morning versus Afternoon Differences During Upwelling Period: Drop Point H

the morning drops while no more than 29% of the recoveries occur in any one sector for the afternoon drops. Drop point C does not show a significant difference in the distribution of returns between morning and afternoon drops.

During the other two oceanic seasons, the number of returns was generally too small to produce a meaningful plot of the data. For drop stations H (not shown) and M (Figure 30), the afternoon drops were further upcoast than those for the morning drops during the Oceanic period. For the Davidson period, drop point S (Figure 31) has its returns spread more widely downcoast for the afternoon drops as compared to the morning drops.

The cause of the difference in returns from morning and afternoon drops appears to be related to the diurnal onshore--offshore coastal wind pattern. It is believed that the morning drops were exposed to the onshore seabreeze for a longer time than the afternoon drops, therefore the morning drops would be expected to move in a more direct path toward the shore while the afternoon drops, after the seabreeze dies down, would be expected to be more dispersed along the coast by any current present. It would, therefore, be expected that the distribution of bottles from afternoon drops would be spread further in the direction of the oceanic component of the current. Because they were less dispersed along the coast, the morning drops might be expected to have a higher return rate than the afternoon drops.

Drop point C is different from the other stations during the Upwelling period apparently because the onshore wind

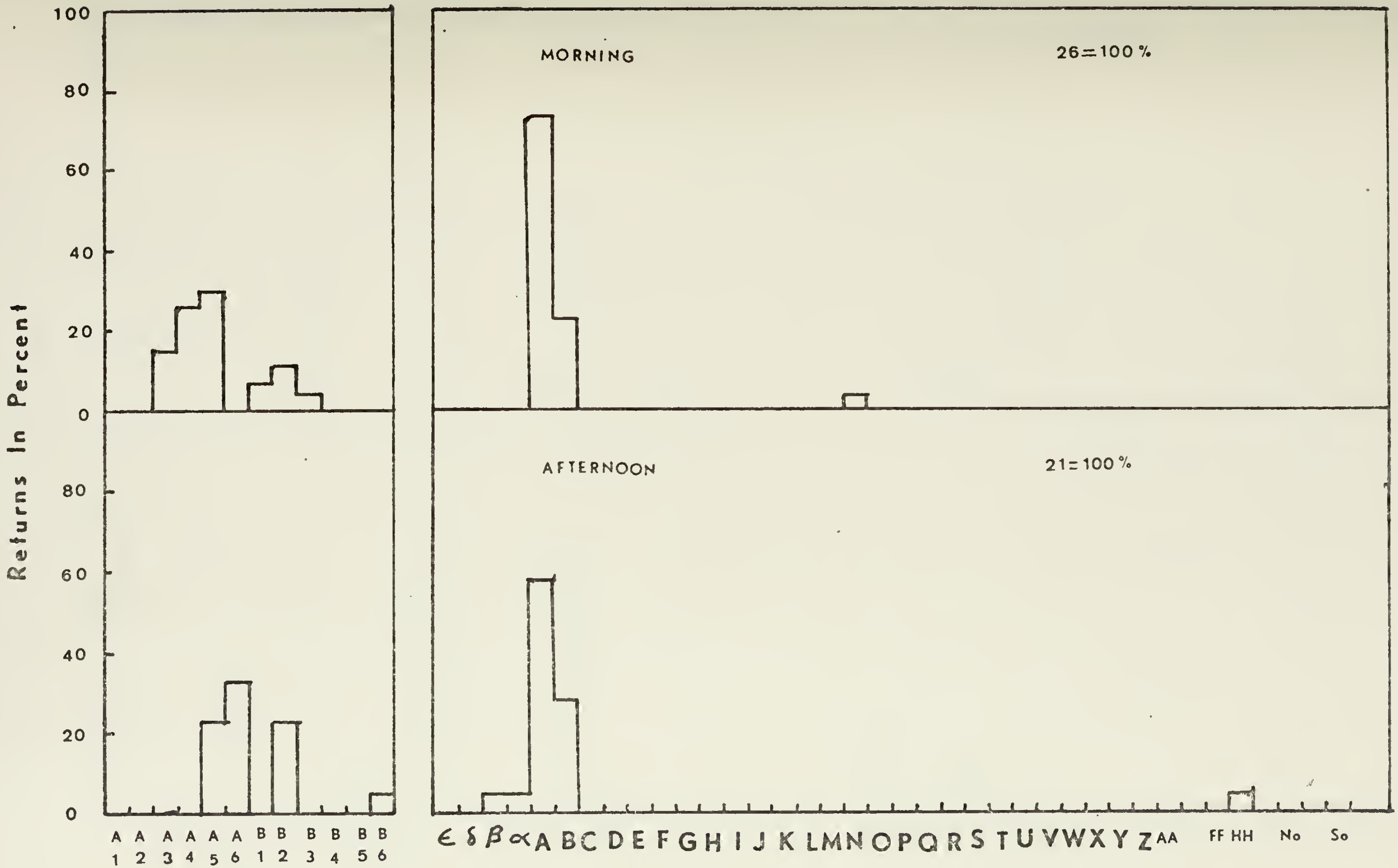

Figure 30. Morning versus Afternoon Differences During Oceanic Period: Drop Point M

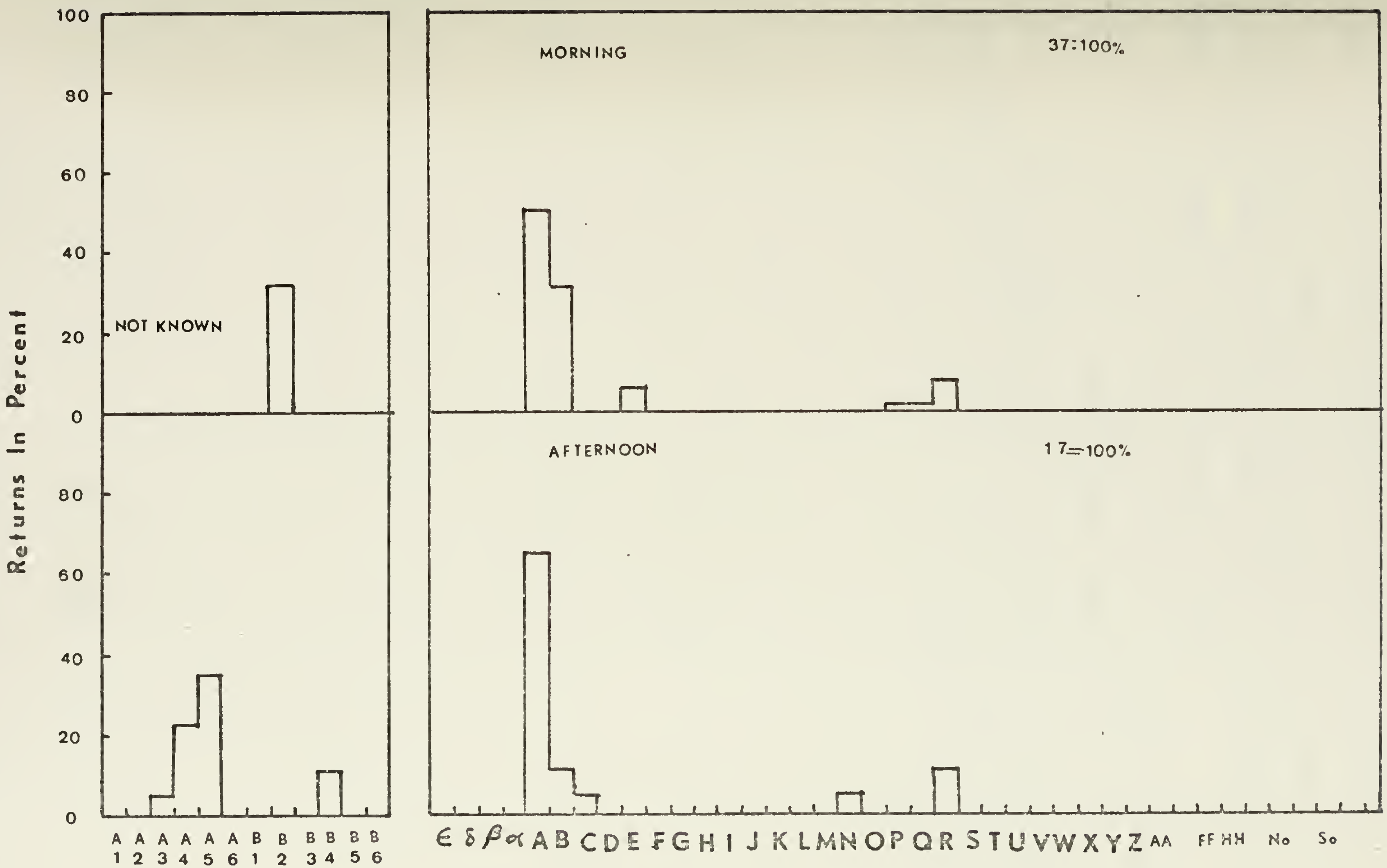

Figure 31. Morning versus Afternoon Differences During Davidson Period: Drop Point S

and the ocean-driven circulation are in the same direction so that the morning and afternoon bottles should travel in the same direction. The difference in the wind effects between the morning and afternoon drops occurs only during the interval between drops, and the longer the bottles remain in the water the smaller this difference becomes.

Of the two major driving forces of the bay circulation, wind is the only one which changes significantly on a daily basis. Thus it appears that the difference in the distribution and number of bottle returns between the morning and afternoon drops is due to the diurnal onshore-offshore wind pattern.

VI. COMPARISON WITH OTHER CURRENT STUDIES

While it is difficult to compare measurements made using different methods and done at different times, there are several studies of the circulation in or near Monterey Bay which are useful for comparison with the results of the drift bottle study. These are described below.

A current drogue study done by Stevenson (1964) is probably the most applicable study for comparison with the drift bottle study since the current measurements were made in the area of drop points M and H of the drift bottle study under various wind conditions. Stevenson observed the simultaneous movement of drogues at depths of 2, 4, 8, and 14 feet for periods not exceeding six hours. He conducted two surveys in August and October 1963 and eight more between January and March 1964.

Stevenson found his drogues to move in directions to the right of the wind for wind directions other than northwest. For moderately strong northwest winds, his drogues moved substantially to the left of the wind direction. These movements were also observed in the drift bottle study. The range of speeds observed by Stevenson is close to the large values of the minimum drift speeds obtained for the drift bottles.

In a period of light winds during the Davidson period, Stevenson's results show the drogue tracks to be much farther to the right of the wind than would be expected for pure wind drift. The extra movement to the right might be due to the

clockwise gyre predicted by the Garcia model for this time of the year and suggested by the drift bottle results. These results are interpreted here as wind drift superimposed on the oceanic component driven by the Davidson Current. It is considered that the diminished wind drift due to weak winds allowed the oceanic component to be more visible than at times of stronger winds. It was concluded in both Stevenson's study and in the drift bottle study that, except during periods of calm, the dominant driving force of the surface circulation is the wind in these shallow waters.

Stoddard (1971), in a study to test the feasibility of shore-based radar in tracking current drogues in Monterey Bay, released a total of 41 parachute drogues. The drogues were set at a mean depth of about 45 feet and were tracked for periods of 6 to 20 hours and occasionally longer. Most of the drops were in the southern bay seaward of the area of the drift bottle drops, but a few were in the northern bay and some seaward of the bay. The period covered in his study was August to November, 1970.

Current speeds measured by the drogues ranged from almost zero to 0.7 knot and were generally between 0.2 and 0.4 knot (10 cm/sec to 20 cm/sec). These mean speeds are close to the largest minimum speeds calculated for the drift bottles; however, they may not be comparable because of the different depths at which the measurements were made.

Stoddard's results seem to indicate a clockwise pattern in the bay during the Davidson Current period and a counter-clockwise gyre during the time of the California Current. The

oceanic current prevailing at these times was determined from drogues tracked seaward of a line between Santa Cruz and Point Pinos. He concluded that the oceanic currents were probably the dominant driving force of the bay circulation, with the possibility of tidal forces being important in the shallower regions of the bay. It should be noted that at the depth at which the drogues were placed the wind-driven effect was probably weak except at times of sustained high winds. It may thus be expected that the effects of the ocean currents should dominate the current pattern. Stoddard's results generally agree with the bay circulation model of Garcia and the drift bottle observations.

Drogue studies were also carried out by personnel of the Naval Postgraduate School and from the Association of Monterey Bay Area Governments (AMBAG) from June to August, 1972 (data provided by AMBAG). In two drogue studies in June and July, a clockwise circulation was indicated for the southern bay. This is opposite to the counterclockwise circulation which is predicted by Garcia's model for the southerly oceanic current expected for this time of year. Drogues tracked in the northern part of Monterey Bay in early August indicate a counterclockwise circulation cell in the northern bay, with flow out of the bay along the northern coast past Santa Cruz and to the northwest. Drogues tracked in late August in both the northern and southern bay appear to indicate a counter-clockwise gyre for the whole bay with flow out of the bay to the north. The distribution of drift bottles found in the northern bay and upcoast from Santa Cruz during the Oceanic period is in agreement with the August circulation pattern.

In June and July, as stated, the results were contrary to Garcia's model if the direction of the ocean current flowing along the open coast is south. The supposition of a southerly ocean current during these months may be incorrect for 1972 since variability was shown to exist from year to year by the CalCOFI drift bottle study (Crowe and Schwartzlose, 1972). Three of the four AMBAG drogue studies appear to indicate a two gyre current pattern while the other indicates a single gyre for the whole bay. The average speeds were similar to those obtained from the drift bottle results. The AMBAG drogues would be expected to show the influence of ocean currents, as Stoddard's results did, rather than wind-driven transport.

A regular CalCOFI drift bottle station is located on the seaward edge of Monterey Bay off Santa Cruz (Crowe and Schwartzlose, 1972). Upon occasion, drift bottle returns from this station suggest a counterclockwise circulation pattern extending from Monterey Bay to Ano Nuevo Point or possibly further north. The drop of April 1956 appears to be good example of this. Five to twelve days after being dropped, bottles were found along the coast north of Santa Cruz to about fifty miles south of San Francisco. 37 to 94 days later bottles from the same drop were found in southern Monterey Bay. The oceanic current at that time appeared to be directed southward according to the returns from other nearby drop stations. This type of circulation pattern is suggested by the drift bottle returns during the Oceanic period and occasionally during the Upwelling period, and also by the AMBAG drogues for late August 1972.

Lammers (1971) and Moomy (1973) deduced the geostrophic circulation of the bay from the temperature structure of the water. The results of these two theses were compared with the bay currents as inferred from the drift bottle study and Garcia's model. Lammers' results appear to agree with the proposed bay circulation pattern for October through April, but differ for the period of May to September. Moomy's results for geostrophic currents determined from surface sigma-t values appear to agree with the current gyres predicted from Garcia's model during all three oceanic seasons, with the drift bottle study, and with a number of the AMBAG drogues tracked at the same time as Moomy's study.

The methods used by Moomy and Lammers may not work at times due to failure of the assumptions for geostrophy. Salinity variations, which were not considered by Lammers, can significantly affect the determination of geostrophic currents. Additionally, Monterey Bay surface currents are weak and may easily be perturbed by local winds, bottom topography, or tidal forces. Changes in offshore eddies or meanders may also cause these approaches to circulation determination to be misleading.

In summary, it appears that other studies of the currents in Monterey Bay generally agree with the results of this thesis. The wind effects noted in Stevenson's measurements are consistent with those observed in the drift bottle study. The seasonal bay circulation patterns believed by this author to be driven by the oceanic currents as proposed by the model

of Garcia are also consistent with the drift bottle results, although the two AMBAG drogue studies of June and July, 1972 and Lammer's summer circulation are in disagreement. The weak and apparently variable nature of the currents may partially account for the observed differences.

VII. CONCLUSIONS

A total of 2100 drift bottles were dropped at five stations in southern Monterey Bay at intervals of about three weeks for a fourteen-month period. 1002 bottles (47.7%) were recovered. Over 99% of the bottles were recovered on the shoreline within Monterey Bay, with most of the recoveries occurring on Del Monte Beach close to the drop points. About 90% of the recoveries took place south of the center of the bay at Moss Landing.

It is apparent that the extreme southern bay retains most of the floating materials released into it. The high concentration of bottle returns from Del Monte Beach coupled with fewer than 1% of the returns from outside the bay indicates that any floating materials released from boats, from Monterey Harbor, through sewage outfalls, or from any other source in the southern bay can be expected to be little dispersed and to drift ashore near the point of introduction. Surface currents are relatively weak, with speeds averaging from 0.2 to 0.4 knots as shown by both drift bottles and drogue studies by other investigators.

A model of the currents in the bay that says the currents are driven by a combination of wind stress acting on the surface water and momentum transfer from the ocean currents flowing offshore of the bay is supported by the drift bottle results for southern Monterey Bay. The transport caused by

local winds is more transient in nature than that believed to be caused by the oceanic currents, although distinctive wind-driven patterns undoubtedly recur such as that associated with the afternoon seabreeze. The wind-driven component and the ocean current driven component sum appear to form the surface current in southern Monterey Bay. Each predominates at different times, but the wind is believed to be the dominant driving force in the drift bottle area. Other components of the current are wave mass transport and tidal currents, but these could not be determined from the drift bottle data and are not believed to be significant factors in the long-term net transport of water in the bay.

Drift bottle returns indicate that the surface current along shore in the southern end of the bay is dominantly counter-clockwise, with easterly flow off Cannery Row and flow upcoast parallel to Del Monte Beach. This circulation pattern appears to be related to winds from the northwest, the predominant wind direction on the coast. The diurnal onshore seabreeze during the afternoon, which is common a large part of the year, is a northwest wind. Northwest winds also occur in association with cyclonic storm systems during the winter season.

The diurnal seabreeze regime appears also to account for the marked differences observed in the drift bottle returns, with the returns from the morning drops being greater in number and being found closer to the release point than the returns from the afternoon drops. These differences are best explained by the fact that while bottles dropped in the

morning usually did not reach the shore on the day of the drop, according to the bottle return times, the bottles from the morning drops would be expected to move closer to the shore in a direction determined by the wind because of the longer exposure to the onshore winds resulting in returns close to the drop point. Bottles released in the afternoon would be under the influence of the seabreeze a shorter period of time and would be expected to drift farther along the coast after the seabreeze has died down. The drift of the afternoon bottles was observed to be in the expected direction of the oceanic component of the current as predicted by the Garcia model for all seasons and drop points examined.

The drift bottle results also showed a variation in the distribution and number of returns with the oceanic current seasons defined by Skogsberg (1936). During the Upwelling period (March to early September), bottle drift appears to be easterly along the north shore of the Monterey Peninsula and then turns northward along Del Monte Beach possibly as part of a counterclockwise gyre in the bay as suggested by the Garcia model. The returns for this season showed a secondary peak north of Moss Landing near Sunset and Palm Beaches, while the region south of Moss Landing for five miles showed very low returns. This suggests a separate circulation may exist in the northern bay with a two gyre pattern possible in the bay, such that one gyre is south of the Monterey Submarine Canyon and the other north of it (Figure 15), as suggested by Garcia. Both gyres would be expected to be counterclockwise during this period.

During the Oceanic period (September to mid-November), the bay circulation appears to be more variable and sluggish. Flow along the coast in the southern bay appears to be counter-clockwise with easterly flow along the shore off Cannery Row and northerly flow off Del Monte Beach. A single counter-clockwise gyre for the whole bay (Figure 14) with flow out of the bay along the coast north of Santa Cruz, is suggested by the absence of a secondary peak of returns, by the return of bottles from the northern part of the bay and to the north of the bay, and the AMBAG drogue tracks for late August, 1972, coupled with the presence of the California Current on the open coast.

During the Davidson period (Mid-November to February), both the bottle returns and the expectation of a northward flowing current on the open coast would agree with a clock-wise circulation in the bay. A strong secondary peak of drift bottle returns from the Sunset-Palm Beach area from all drop points strongly suggests a separate circulation in the northern bay with the Garcia model suggesting the possibility of a two-gyre pattern (Figure 16). Both gyres should be clockwise and are believed to be situated such that one is south of the submarine canyon and the other north.

Stevenson's (1964) drogue studies off Del Monte Beach are in agreement with the observations of the drift bottle study in regard to the angular deviation of the wind-driven current at the surface from the wind direction, and also in regard to the effect of the presence of the coastal boundary formed by the Monterey Peninsula on the currents caused by

northwest winds in the southern bay. Parachute drogue studies by Stoddard (1971) and AMBAG carried out at depths of over 40 feet suggest that ocean currents rather than wind dominate at these depths in driving the bay circulation. This is plausible since wind effects decrease rapidly with depth, causing other components of the current to be relatively more important than they are at the surface. Most of these deep drogues behaved in the manner predicted by Garcia's (1971) model of the circulation driven by ocean currents off the bay.

Further investigation of the circulation patterns in Monterey Bay is needed. In addition, tidal currents and wave transport in the bay should be examined in more detail.

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APPENDIX A. DRIFT BOTTLE RETURNS BY DROP DATE

Number and Percent of Returns from each Drop Station

Drop No.	Date	AM	PM	C	%	B	%	S	%	M	%	H	%	TOTAL	%
1	4-11-63	X		9	75	7	58.3	9	75	7	58.3	12	100	44	73.3
2	4-11-63		X	10	83.3	7	58.3	9	75	9	75	5	41.7	40	66.7
3	5-2-63	X		4	33.3	5	41.7	12	100	12	100	12	100	45	75
4	5-2-63		X	6	50	8	66.7	6	50	8	66.7	4	33.3	32	53.3
5	5-23-63	X		4	33.3	2	16.7	4	33.3	3	25	2	16.7	15	25
6	5-23-63		X	2	16.7	1	8.3	2	16.7	5	41.7	2	16.7	12	20
7	6-13-63	X		8	66.7	4	33.3	10	83.3	4	33.3	6	50	32	53.3
8	6-13-63		X	2	16.7	7	58.3	4	33.3	5	41.7	1	8.3	19	31.6
9	7-25-63	X		6	50	4	33.3	4	33.3	8	66.7	12	100	34	56.7
10	7-25-63		X	4	33.3	11	91.7	9	75	8	66.7	6	50	38	63.3
11	8-15-63	X		7	58.3	6	50	4	33.3	8	66.7	11	91.7	36	60
12	8-15-63		X	6	50	6	50	4	33.3	6	50	3	25	25	41.7
13	9-5-63	X		0	0	7	58.3	8	66.7	7	58.3	6	50	28	46.7
14	9-5-63		X	4	33.3	5	41.7	9	75	9	75	6	50	33	55
15	9-26-63	X		5	41.7	0	0	2	16.7	3	25	5	41.7	15	25
16	9-26-63		X	5	41.7	2	16.7	2	16.7	1	8.3	0	0	10	16.7
17	10-17-63	X		2	16.7	9	75	1	8.3	10	83.3	6	50	28	46.7
18	10-17-63		X	1	8.3	1	8.3	3	25	8	66.7	5	41.7	18	30
19	11-7-63	X		7	58.3	0	0	1	8.3	8	66.7	7	58.3	23	38.3
20	11-7-63		X	3	25	4	33.3	1	8.3	3	25	1	8.3	12	20
21	12-19-63	X		7	58.3	2	16.7	12	100	2	16.7	10	83.3	33	55
22	12-19-63		X	3	25	0	0	5	41.7	3	25	4	33.3	15	25
23	1-9-64	X		0	0	3	25	10	83.3	9	75	12	100	34	56.7
24	1-9-64		X	0	0	1	8.3	6	50	12	100	9	75	28	46.7
25	1-30-64	X		1	8.3	2	16.7	9	75	10	83.3	8	66.7	30	50
26	2-20-64	X		7	58.3	7	58.3	8	66.7	7	58.3	5	41.7	34	56.7
27	2-20-64		X	6	50	5	41.7	6	50	5	41.7	6	50	28	46.7
28	3-12-64	X		8	66.7	11	91.7	9	75	12	100	8	66.7	48	80
29	3-12-64		X	9	75	11	91.7	8	66.7	9	75	11	91.7	48	80
30	4-2-64	X		6	50	4	33.3	1	8.3	5	41.7	0	0	16	26.7
31	4-2-64		X	4	33.3	1	8.3	0	0	8	66.7	1	8.3	14	23.3
32	4-23-64	X		7	58.3	0	0	1	8.3	10	83.3	11	91.7	29	48.3
33	4-23-64		X	10	83.3	2	16.7	2	16.7	8	66.7	9	75	31	51.7
34	5-14-64	X		8	66.7	8	66.7	11	91.7	12	100	2	16.7	41	68.3
35	5-14-64		X	5	41.7	7	58.3	5	41.7	9	75	9	75	35	58.3
TOTAL				176	41.9	160	38.1	197	46.9	253	60.0	217	51.7	1002	47.7

Bottle drop data: 12 bottles per drop station per drop; Total bottles per station, 420, Total bottles dropped, 2100

APPENDIX B. DRIFT BOTTLE RETURN LOCATIONS BY DROP DATE

1. Drop Point C

Drop No.	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	B 4	B 5	B 6
1												
2												
3												
4												
5												
6												
7												1
8												
9											1	
10												
11												
12												
13												
14					1		1				1	
15			1				2	1				
16												
17			1	1								
18												
19	1		2	2			2					
20		1										
21		3		1	1							
22												
23 *												
24 *												
25												
26												
27												
28										1		
29												
30							4	2				
31				1			1	1	1			
32									3	2		2
33									1	1	3	5
34												
35												
TOTAL	1	4	4	5	2	0	10	4	5	4	5	8

Drop No.	ε	δ	β	α	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1																2			1			2	3			1
2																					1	2	5	1	1	
3									2	1	1															
4								3		2												1				
5									2		1	1														
6									1	1																
7						1	6																			
8	1	1																								
9						1	1			2		1										1				
10							2		1	1																
11					3	4																				
12					3	3																				
13																										
14					1	2	1																			
15					1	3	1																			
16										1			2		1		1									
17					2																					
18			1																							
19					5	2																				
20				2	1																					
21				2	5																					
22		3																								
23 *																										
24 *																										
25					1																					
26						3	1															2				
27									1									2				2	1			
28				1		1		2	3	1																
29								7	2																	
30						6																				
31					1	3																				
32						7																				
33						10																				
34							1	2	1	1					1			1								
35				1						3	1															
TOTAL	1	4	1	6	23	46	13	14	13	13	3	2	2	0	2	2	1	3	1	0	1	10	9	1	1	1

Drop No.	W	X	Y	Z	AA	BB	CC	FF	GG	HH	Other
1–35											
TOTAL	0	0	0	0	0	0	0	0	0	0	0

* No Returns

2. Drop Point B

Drop No.	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	B 4	B 5	B 6	ε	δ	β	α	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB	CC	DD	EE	FF	Other (outside bay)
1	2										1						2	1										1	1					1	1														
2																									1		3	1	1				1																
3								4	1									5																															
4																					1	6			1																								
5																					2																												
6																						1																											
7																			3																														
8																			1		1	1		1					1	1																			1S
9							2	1										3	1																														
10																					1		1	7							1			1															
11						1					5						1	5																															
12						1											1	5																															
13	2			1	1		2										4	2	1																														
14								1										1	2		1																												
15 *																																																	
16																																																	1N
17						4	2	1	2								4	5																															
18														1																																			
19 *																																																	
20							1								1	1		1					1																										
21					2												2																																
22 *																																																	
23	1				1												2																		1														
24															1																																		
25			1												1		1																																
26																					3				1					1				1															
27																							1							1				2	1														
28																				6	5																												
29																				7	4																												
30											3	1						4																															
31																			1																														
32 *																																																	
33																											2																						
34									3	3		1						7	1																														
35																			3	1					1																		1					1	
TOTAL	5	0	1	1	4	6	7	7	6	3	9	2	0	1	3	1	17	39	13	14	13	8	3	8	4	0	5	2	3	3	1	0	1	5	3	0	0	0	0	0	0	0	1	0	0	0	0	1	2 (1S, 1N)

* No Returns

3. Drop Point S

Drop No.	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	B 4	B 5	B 6	ε	δ	β	α	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	Other Outside Bay
1							2		3	1								6	1											1			1											
2											1							1	2							1		1		1														
3									11	1								12																										
4												4						4				2																						
5																					4																							
6																					2																							
7											8	1						9	1																									
8											1							1	3																									
9							1	2	1									4																										
10												4						4	4			1																						
11											4							4																										
12																		4																										
13					2			1	5								2	6																										
14							2	7										9																										
15												1						1																										1N
16																								1	1																			
17					1												1																											
18																			3																									
*19																																												
20							1											1																										
21								12										12																										
22					5												5																											
23				3	6												9																											
24			1	4	1												6																											
25																	9																											
26																					2											1	1	3										
27										2								2	1											1				2										
28				1						8							1	8																										
29										6		1						7	1																									
30												1						1																										
*31																																												
32																																						1						
33																			1				1																					
34											5	6						11																										
35																			5																									
TOTAL	0	0	1	8	15	0	6	22	20	18	19	18	0	0	0	0	33	107	22	0	8	3	1	1	1	1	0	1	0	3	0	1	2	5	0	0	0	1	0	0	0	0	0	1

* No Returns

4. Drop Point M

Drop No.	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	B 4	B 5	B 6	ε	δ	β	α	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	HH	Outside Bay
1		1															1		1						1		2																		
2											1							1	2								1				1			2											
3					8	2	2										10	2																											
4																				2	2	2			1		1																		
5																					3																								
6																			2		3																								
7										1		1						2	1		1																								
8										1								1				2		1						2															
9		1	2		1							1					4	1	1	1																									
10								4		1								5				1		1												1									
11					1				2		5						1	7																											
12																	1	5																											
13					3			2									3	2																											
14					4	3		1				1					7	2																											
15							1		1									2												1															
16					1												1																												
17			4	1	5												10																												
18						4		4									4	4																											
19				6			1	1									6	2																										1	
20															1	1																													
21					2												2																												
22											2				1			2																											
23		5			4												9																												
24				12													12																												
25																	10																												
26										1								1	4		1													1											
27																																1		1	2		1								
28					12												12																												
29																					7	1	1																						
30				1			2		1			1					1	4																											
31				1			1	1	5								1	7																											
32								6	4									10																											
33											1	6						7	1																										
34					5	7											12																												
35									3	1		2						6	2								1																		
TOTAL	0	7	6	21	46	16	7	19	16	5	9	12	0	0	2	1	107	73	14	3	17	6	1	2	2	0	5	0	0	3	1	1	0	4	2	1	1	0	0	0	0	0	0	1	0

5. Drop Point H

Drop No.	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	B 4	B 5	B 6	ε	δ	β	α	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	5																12																									
2	3		1														4								1																	
3			11	1													12																									
4											1							1	1		1						1															
5																						1	1																			
6																					1		1																			
7												1						1	4												1											
8																									1																	
9	1	8	2			1											12																									
10	1		1					2									2	2														1	1									
11						1	1										5	5						1																		
12																	1	1																								
13			2	1	2			1									5	1																								
14			2							2							2	2			1																					
15	3		1														4		1																							
16*																																										
17		1	2	1			1			1							4	2																								
18						1		1	2			1					1	4																								
19		2		3				2									5	2																								
20															1																											
21																	10																									
22	1	1			2												4																									
23		12															12																									
24	5		1	3													9																									
25	3		1		3											1	7																									
26																									1								1	2	1							
27																					2		1				1				1			1								
28				8													8																									
29																			1	5	5																					
30*																																										
31						1											1																									
32					8	2				1							10	1																								
33							6		2			1						9																								
34							1											1	1																							
35					4	2											6					2																				
TOTAL	22	24	24	17	19	8	9	6	4	4	1	3	0	0	1	1	136	32	8	5	10	3	3	1	3	0	2	0	0	0	2	1	2	3	1	0	0	0	0	0	0	0

* No Returns

APPENDIX C. DRIFT BOTTLE TRAVEL TIMES

TRAVEL TIME BY DROP NUMBER AND STATION (hours)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
	C				1		5	2		1
	B		1	1		1	3		1	
	S		5			1	2			1
1	M			1			2	1		1
	H	5								
	TOTAL	5	6	2	1	2	12	3	1	3
	C					3	4	2	1	
	B					3	2			2
	S				1	3	1	1		
2	M				1	3	1		2	
	H	1		4						
	TOTAL	1	0	4	2	12	9	3	3	2
	C					3		1		
	B		5							
	S	11	1							
3	M	12								
	H	12								
	TOTAL	35	6	0	0	3	0	1	0	0
	C				1	1	1	3		
	B				7				1	
	S			4				2		
4	M				1	3		3		
	H				2	1		1	1	
	TOTAL	0	0	4	11	5	1	9	2	0

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
5	C			1		3				
	B						2			
	S					2	2			
	M					1	1			1
	H					2				
	TOTAL	0	0	1	0	8	5	0	0	1
6	C				1	1				
	B				1					
	S					2				
	M			1	2	1	1			
	H					1	1			
	TOTAL	0	0	1	4	5	2	0	0	0
7	C				4	4				
	B					3				
	S	9	1							
	M			1	1	1	1			1
	H				1	1	4			
	TOTAL	9	1	1	6	9	5	0	0	1
8	C							2		
	B					4	1	1		2
	S			2	2					
	M					1	4			
	H						1			
	TOTAL	0	0	2	2	5	6	3	0	2

APPENDIX C (continued)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
9	C				1	3	1		1	
	B	1	1	2	2					
	S			3						
	M					2	1	4		
	H	11	1							
	TOTAL	12	2	5	3	5	2	4	1	0
10	C				1		1	1		
	B			2		7			1	1
	S	1		6		3				
	M			4		1	1	1		1
	H			1		3	1	1		
	TOTAL	1	0	13	1	14	3	3	1	2
11	C			7						
	B		2	3	1					
	S			4						
	M		2	1	5					
	H			10		1				
	TOTAL	0	4	25	6	1	0	0	0	0
12	C			1	1	2				
	B			1	1					
	S			4						
	M	1		4						
	H				1				1	1
	TOTAL	1	0	10	3	2	0	0	1	1

APPENDIX C (continued)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
	C			3		2				
	B			1					1	
	S	6	1							
13	M		2	2		1	2	1		
	H			2		3	1	2		1
	TOTAL	6	3	8	0	6	3	3	1	1
	C			1		1				
	B			1			2	2	1	
	S			9						
14	M	7		1		1				
	H						1		1	
	TOTAL	7	0	12	0	2	6	2	2	0
	C			3		2	1			
	B									
	S			1		1			1	
15	M	1		1						
	H		3	2						
	TOTAL	1	3	7	0	3	1	0	1	0
	C						3			
	B								1	
	S									
16	M				1					
	H				1					
	TOTAL	0	0	0	2	0	3	0	1	0

APPENDIX C (continued)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
17	C				1		1			
	B				9					
	S	1								
	M	1	9							
	H		2	2	1			1		
	TOTAL	2	11	2	11	0	1	1	0	0
18	C									
	B					1				
	S			2				1		
	M			6	1	1				
	H					5				
	TOTAL	0	0	8	2	7	0	1	0	0
19	C			2		5				
	B									
	S									
	M		6	1				1		
	H		4	1		1	1			
	TOTAL	0	10	4	0	6	1	1	0	0
20	C							2		
	B			2		2		1		
	S			1						
	M					1		1		
	H					1				
	TOTAL	0	0	3	0	4	0	4	0	0

APPENDIX C (continued)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
21	C			1	2	2	1		1	
	B				2					
	S		12							
	M			2						
	H	6	3		1					
	TOTAL	6	15	3	5	2	1	0	1	0
22	C				3					
	B									
	S	1			5					
	M	4			2	1				
	H		11	2	2					
	TOTAL	5	11	2	12	1	0	0	0	0
23	C									
	B								1	
	S			6	2					
	M			5		1				
	H			1						
	TOTAL	0	0	12	2	1	0	0	1	0
24	C									
	B			1						
	S			3	2					
	M			12						
	H			6	2	1				
	TOTAL	0	0	22	4	1	0	0	0	0

APPENDIX C (continued)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
25	C					1				
	B							2		
	S			8		1				
	M			10						
	H			4	2	2				
	TOTAL	0	0	22	2	4	0	2	0	0
26	C					5		5		
	B					3	1	3	1	
	S					2		2		
	M			2		4		3	2	
	H							3		
	TOTAL	0	0	2	0	14	1	16	3	0
27	C					1		1	1	
	B							1	2	
	S				1	1		2	2	
	M									1
	H				3	1		3	2	1
	TOTAL	0	0	0	4	3	0	7	7	2
28	C		1		1	5				
	B				11					
	S			9						
	M	12								
	H		8							
	TOTAL	12	9	9	12	5	0	0	0	0

APPENDIX C (continued)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
	C				9					
	B				11					
	S			7	1					
29	M				7				1	
	H				11					
	TOTAL	0	0	7	39	0	0	0	1	0
	C		1	4		1				
	B			1		1	1		1	
	S			1						
30	M			2	2					
	H									
	TOTAL	0	1	8	2	2	1	0	1	0
	C			3		1				
	B			1						
	S									
31	M			7		1				
	H									1
	TOTAL	0	0	11	0	2	0	0	0	1
	C		2	2		3				
	B									
	S									1
32	M		5			5				
	H	7	3			1				
	TOTAL	7	10	2	0	9	0	0	0	1

APPENDIX C (continued)

DROP NO.	STATION	0-5	6-10	11-30	31-50	51-100	101-200	201-300	301-600	> 600
33	C			6	1	3				
	B							2		
	S			1		1				
	M			6		1	1			
	H	6		2		1				
	TOTAL	6	0	15	1	6	1	2	0	0
34	C			2	1	2	1			
	B			6	1					
	S			9	1					
	M	2	10							
	H	1		1						
	TOTAL	3	10	18	3	2	1	0	0	0
35	C	2				1	1	1		
	B			4				1	2	
	S	5								
	M			6		1				
	H	1		5		2				
	TOTAL	8	0	15	0	4	1	2	2	0
TOTAL BOTTLES		127	100	254	143	153	69	67	29	18
PERCENT		13.3%	10.4%	26.5%	14.9%	16.0%	7.1%	6.9%	3.0%	1.9%
CUMULATIVE PERCENT		13.3%	23.7%	50.2%	65.1%	81.1%	88.2%	95.1%	98.1%	100%

APPENDIX D. BOTTLE DRIFT SPEEDS

Five Largest Speeds from Each Drop

Speeds in cm/sec

DROP	1	2	3	4	5
1	15.9	8.0	7.8	7.3	6.5
2	10.6	8.6	8.6	8.3	7.9
3	13.6(6)	13.3	12.9(7)	12.3(3)	11.3
4	8.7	5.3	4.9	4.8	4.6
5	4.5	4.4	3.9	2.8	2.7
6	5.1	4.9	4.3	4.1	3.4
7	7.7	7.4(5)	5.4	5.3	4.0
8	19.9*	4.5	4.0	3.6	3.5
9	18.8	14.6	12.9(4)	11.8	6.4
10	10.2	10.0	5.9	4.0(6)	3.7
11	5.0	4.6	3.4	3.2	2.6
12	4.9	4.0	3.2	2.5	2.2
13	6.5	6.4	6.2	5.7	5.6
14	17.9	5.0(4)	4.4	4.3(2)	3.9
15	8.8	8.0	6.9	3.6*	3.3(2)
16	7.5*	6.5	6.0	4.9(2)	4.0
17	11.2	9.2	5.4(3)	4.4(3)	3.9
18	3.9*	3.0	1.3(2)	1.2(4)	
19	9.3(2)	4.4(2)	4.3(6)	3.3(2)	1.2(2)
20	5.4	3.2	2.9	2.4	2.0
21	4.4(6)	3.4(3)	2.8(12)		
22	6.1*	5.9*	5.7*	1.7	1.3(5)
23	4.7(4)	3.7(11)	2.7(6)		
24	4.1	3.2(3)	1.7	1.5	1.3
25	4.3	3.5	3.4	1.8(2)	1.6(3)
26	4.1	3.5	3.2	3.0(2)	2.9
27	8.4	6.5	5.1	3.6	3.2
28	6.4(12)	5.1(8)	4.2	3.8	3.6
29	4.4(2)	4.3(2)	4.1	4.0(6)	3.8(2)
30	9.0	3.5(4)	2.4	1.1	
31	4.7	3.8	3.3	3.2	2.8
32	11.2	11.0	10.1	9.4(5)	8.9
33	6.3	4.7(4)	4.6(2)	3.9	2.5(6)
34	10.7	5.9	5.8	5.3	5.0
35	13.4(2)	8.0	7.3(5)	6.3	4.9

*Outside Bay

Number of bottles is shown in parenthesis where more than one.

APPENDIX E. DRIFT BOTTLE RETURNS BY OCEANIC SEASON

Figures are Number of Bottles Returned

Coastal sectors A1 – H:

	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	B 4	B 5	B 6	ε	δ	β	α	A	B	C	D	E	F	G	H
DROP POINT C																								
Upwelling Season																								
TOTAL				1			5	3	5	4	4	8	1	1	0	1	7	36	10	14	12	12	3	2
MORNING							4	2	3	3	1	3				1	3	20	8	4	8	5	2	2
AFTERNOON				1			1	1	2	1	3	5	1	1			4	16	2	10	4	7	1	
Davidson Season																								
TOTAL		3		1	1									3		2	6	3	1		1			
Oceanic Season																								
TOTAL	1	1	4	3	1		5	1			1				1	2	10	7	2			1		
DROP POINT B																								
Upwelling Season																								
TOTAL	2					2	2	5	4	3	9	2					4	30	10	14	14	8	1	8
MORNING						1	2	5	4	3	9	2					3	25	5	6	7			
AFTERNOON						1											1	5	5	8	7	8	1	8
Oceanic Season																								
TOTAL	2			1	1	5	5	2	2					1		1	8	9	3		1		1	
Davidson Season																								
TOTAL	1		1		3										2		5				3		1	

Coastal sectors I – Outside Bay:

	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	AA	FF	HH	N_O Outside Bay	S_O Outside Bay
DROP POINT C																			
Upwelling Season																			
TOTAL			1	2		1	1		1	6	8	1	1	1					
MORNING			1	2		1	1			3	3			1					
AFTERNOON									1	3	5	1	1						
Davidson Season																			
TOTAL						2				4	1								
Oceanic Season																			
TOTAL	2		1		1														
DROP POINT B																			
Upwelling Season																			
TOTAL	3		5	2	3	1	1		1	2	1				1	1			1
MORNING				1	1					1	1								
AFTERNOON	3		5	1	2	1	1		1	1					1	1			1
Oceanic Season																			
TOTAL																		1	
Davidson Season																			
TOTAL	1					2				3	2								

COASTAL SECTOR

APPENDIX E (continued)

	A 1	A 2	A 3	A 4	A 5	A 6	B 1	B 2	B 3	B 4	B 5	B 6	ε	δ	β	α
DROP POINT S																
Upwelling Season																
TOTAL				1			3	2	15	16	19	17				
MORNING							3	2	15	10	17	8				
AFTERNOON				1						6	2	9				
Oceanic Season																
TOTAL					3		3	8	5			1				
Davidson Season																
TOTAL			1	7	12			12		2						
MORNING				3	6			12								
AFTERNOON			1	4	6					2						
DROP POINT M																
Upwelling Period																
TOTAL		2	2	2	27	9	5	11	15	4	7	11				
MORNING		2	2	1	27	9	4	6	7	1	5	3				
AFTERNOON				1			1	5	8	3	2	8				
Oceanic Period																
TOTAL			4	7	13	7	2	8	1			1			1	1
MORNING			4	7	8		2	3	1							
AFTERNOON					5	7		5				1			1	1
Davidson Period																
TOTAL		5	12	6						1	2				1	
MORNING		5		6						1					1	
AFTERNOON			12								2					

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	AA	FF	HH	N_O Outside Bau	S_O Outside Bau
DROP POINT S																											
Upwelling Season																											
TOTAL	1	76	18		6	3	1			1		1		2			1					1					
MORNING		55	2		4					1				1			1					1					
AFTERNOON	1	21	16		2	3	1					1		1													
Oceanic Season																											
TOTAL	3	17	3					1	1																	1	
Davidson Season																											
TOTAL	29	14	1		2									1		1	1	5									
MORNING	18	12			2											1	1	3									
AFTERNOON	11	2	1											1				2									
DROP POINT M																											
Upwelling Period																											
TOTAL	43	58	10	3	16	6	1	2	2		5			2	1			2		1							
MORNING	41	26	3	1	4				1		2																
AFTERNOON	2	32	7	2	12	6	1	2	1		3			2	1			2		1							
Oceanic Period																											
TOTAL	31	12												1													
MORNING	19	6												1													
AFTERNOON	12	6																									
Davidson Period																											
TOTAL	33	3	4		1										1			2	2	1					1		
MORNING	21	1	4		1													1									
AFTERNOON	12	2													1			1	2	1					1		

COASTAL SECTOR

APPENDIX E (continued)

DROP POINT H

	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	ε	δ	β	α	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	AA	FFHH	N_O	S_O Outside Bay
Upwelling Period																																										
TOTAL	10	8	15	9	12	7	8	2	2	1	1	2					73	21	7	5	7	3	2	1	2		1				1	1	1									
MORNING	6	8	13	9	8	4	2			1		1					59	8	5			1	1	1							1											
AFTERNOON	4		2		9	3	6	2	2		1	1					14	13	2	5	7	2	1		2		1					1	1									
Oceanic Period																																										
TOTAL	3	3	7	5	2	1	1	4	2	3		1			1		21	11	1		1																					
MORNING	3	3	5	5	2		1	3		1		1					18	5	1																							
AFTERNOON			2			1		1	2	2					1		3	6			1																					
Davidson Period																																										
TOTAL	9	13	2	3	5											1	42				2		1		1		1				1		1	3	1							
MORNING	3	12	1		3											1	29								1								1	2	1							
AFTERNOON	6	1	1	3	2												13				2		1				1				1			1								

COASTAL SECTOR

APPENDIX E (continued)

Summary: Returns by Oceanic Seasons

DROP POINT	Upwelling Period TOTAL	Upwelling Period MORNING	Upwelling Period AFTERNOON	Oceanic Period TOTAL	Oceanic Period MORNING	Oceanic Period AFTERNOON	Davidson Period TOTAL	Davidson Period MORNING	Davidson Period AFTERNOON
C	52.1%(125)	55.8%(67)	48.3%(58)	28.2%(27)	29.2%(14)	27.1%(13)	28.6%(24)	31.2%(15)	25.0%(9)
B	46.6%(112)	42.4%(51)	50.8%(61)	29.2%(28)	33.0%(16)	25.0%(12)	23.8%(20)	29.2%(14)	16.7%(6)
S	47.6%(14)	54.1%(65)	40.8%(49)	28.2%(27)	25.0%(12)	31.2%(15)	66.7%(56)	81.3%(39)	47.3%(17)
M	65.0%(156)	67.5%(81)	62.5%(75)	51.0%(49)	58.3%(28)	43.7%(21)	57.1%(48)	58.3%(28)	55.6%(20)
H	52.9%(127)	63.3%(76)	42.3%(51)	37.5%(36)	50.0%(24)	25.0%(12)	64.3%(54)	73.0%(35)	52.8%(19)

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DOCUMENT CONTROL DATA - R & D

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1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP
3. REPORT TITLE A Drift Bottle Study of the Southern Monterey Bay	
4. DESCRIPTIVE NOTES (Type of report and, inclusive dates) Master's Thesis; September 1973	
5. AUTHOR(S) (First name, middle initial, last name) Jeffrey Alan Reise	
6. REPORT DATE September 1973	7a. TOTAL NO. OF PAGES 113 / 7b. NO. OF REFS 18
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.	
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

2100 drift bottles were dropped at five stations in southern Monterey Bay twice per drop day over a period of 14 months. 47.7% (1002) were recovered. Over 99% of the recoveries were made in the bay. The indicated circulation in the southern bay agrees with models driven by wind stress and momentum transfer from the offshore ocean currents. A significant difference was found between the morning and afternoon drops with the morning drop returns being larger and found closer to the drop point. The afternoon returns were more widely dispersed in the direction of the ocean-driven component of the coastal current. The diurnal variation of the bottle returns is attributed to the diurnal seabreeze regime. The predominant northwest winds, modified by the seabreeze, appear to generate a counterclockwise circulation along the coast in the southern end of the bay. The drift bottles seem to follow the coastal portion of the Garcia (1971) model of the ocean-driven component of the circulation. This is counterclockwise with the California Current flowing offshore and clockwise when the Davidson Current flows. Current velocities appear to be between 0.2 and 0.4 knots.

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S/N 0101-807-6811

Unclassified
Security Classification

A-31408

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Drift-bottle study						
Monterey Bay circulation						
Currents in Monterey Bay						
Seasonal variation in coastal currents						
Diurnal variation in coastal currents						

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